

FINAL REPORT

Demonstration Program for Low-Cost, High-Energy-Saving
Dynamic Windows

ESTCP Project EW-201252

JULY 2017

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View, Inc.

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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
AT/FP	Anti-Terrorism/Force Protection
BTU	British thermal unit
CRADA	Collaborative Research and Development Agreement
DC	direct current
DBOM	Design/build/operate/maintain
DoE	U.S. Department of Energy
ECIP	Energy Conservation Investment Program
EEM Suite	Enterprise Energy Management Suite
ERBSIC	Electricity, Resources, and Building Systems Integration Center of NREL
ESCOs	Energy service companies
ESPC	Energy Savings Performance Contracts
ESTCP	Environmental Security Technology Certification Program
FARs	Federal Acquisition Regulations
FEMP	Federal Energy Management Program
GHG	Greenhouse gases
GSA	General Services Administration
HVAC	Heating, ventilation, air-conditioning
IGU	Insulated glass unit
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
Low-e	low emissivity
M&V	Measurement and verifications
MCAS	Marine Corps Air Station
MELs	Miscellaneous equipment loads
MEP	Mechanical, Electrical, Plumbing
MILCON	Military construction
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
PO	Performance objectives
PV	Photovoltaic

PVB	Polyvinyl butyral
PVD	Physical vapor deposition
ROICC	Resident Officer In Charge of Construction
SHGC	Solar heat gain coefficient
S/RM	Sustainment, Restoration, and Modernization program
Sqft	square feet
TMY	Typical meteorological year
V	volts

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A final thanks goes to the ESTCP program and their vision of bringing forth technologies that will provide both energy security and a more sustainable future to our military infrastructure.

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EXECUTIVE SUMMARY

ENERGY PROBLEM

Inefficient windows in buildings represent one of the biggest energy problems in the military today. Facilities consume 30% of all Department of Defense (DOD) energy demand¹. This massive energy footprint costs taxpayers billions of dollars each year and impacts DOD mission assurance by straining fragile public electricity grids.

In the United States, over 50% of building energy is used for cooling, heating and lighting², all of which are directly impacted by windows. The thermal envelope impacts about 56% of total commercial energy consumption. Windows are considered to be the “Achilles Heel” of the building envelope. They allow unwanted solar heat to enter during the summer via radiation and conduction, increasing cooling energy requirements and peak loads. Current windows also allow internal heat to escape during the winter increasing season heating. Beyond negative energy impacts, current windows allow glare to reduce occupant comfort, allow for the over-use of window blinds, and the over-use of artificial lighting energy.

TECHNOLOGY OPPORTUNITY

Electrochromic, or ‘dynamic’ glass, represents a promising technology for the reduction of energy use in DOD buildings. Dynamic glass windows are manufactured with an electrochromic coating enabling them to electronically change their visual and solar heat gain characteristics. A previous ESTCP project demonstrated the capability of dynamic glass for meaningful whole building energy savings that included HVAC savings of 29% and potential artificial lighting savings of up to 62%^{3,4}. However, the installation of dynamic glass required full demolition and replacement of the existing windows. This level of construction activity involved high construction expenses and the displacement of occupants, adding to the final financial cost of the project.

An alternate installation method, termed ‘dynamic in-fill’, may offer a method for reducing deployment costs while retaining the energy and non-energy benefits of dynamic glass. Dynamic In-Fill is a method of installing an additional, non-structural window unit interior to the existing window. It adds insulative glass and air layers and it enables the glass to actively change its performance in response to the environment or user preferences. It does not require demolition of the original window or displacement of occupants in operational facilities. In this way, dynamic in-fill has the potential to remove these primary barriers to adoption of dynamic windows for DOD installations, while increasing the viability of this window technology with traditional ESPCs. If broadly adopted, this technology could reduce global DOD facility energy consumption by up to 10% with total facilities peak load reductions of up to 25%. Such reductions, broadly implemented could ease existing strain on the national grid. Overall, this technology addresses two of DOD’s three key installation energy goals: 1) reduce energy usage/intensity and 2) improve energy security.

In addition to energy savings, one of the major economic benefits of dynamic windows is the possible capital-savings and maintenance-savings from down-sizing HVAC systems that is enabled by the reduced heating and cooling peak-load with installed Dynamic In-Fill windows. The full-scale field data generated in this demonstration project and subsequent calibrated model allowed the team to quantify and validate this reduction in HVAC capacity, enabling the building designers to down-size future HVAC systems without risk.

SCOPE OF THE DEMONSTRATION

The purpose of this demonstration project was to demonstrate the energy and capital savings enabled by View dynamic windows by performing a limited scope retrofit at the National War College in Washington DC. Over the course of the project, the team developed a detailed energy-model for the demonstration site, with and without dynamic windows. The team then installed monitoring equipment in the demonstration site and performed baseline energy measurements. This data was then used to calibrate the baseline energy models and extrapolate energy consumption back over an annual period. That extrapolated energy model was verified against measured building energy consumption.

The team then retrofitted 58 existing windows with Dynamic In-Fill glass units while the building remained occupied and operational. The installation took under 1 month and was followed by months of energy and occupant monitoring. These results were used to further refine the energy models and then the modeled results were annualized to determine the total annual impact of Dynamic In-Fill windows. From this data we were able to quantify total lifecycle cost, energy savings and GHG reductions relative to upgrading to state-of-the-art low-e windows at the host site.

DEMONSTRATION RESULTS

The project demonstrated a reduction in HVAC energy consumption of 6900 kWh or 6% compared to the existing windows baseline. Peak HVAC loads were reduced by 23% allowing for significant HVAC system downsizing and cost savings during their next maintenance cycle. Additionally, the daily peak cooling requirement shifted from 1 PM (typical of existing DOD buildings) to approximately 5 PM, allowing off occupancy, tapered conditioning. The reduced peak loads and load shift allowed for better system balancing (hot vs. cold offices) for the entire building. Office temperatures were cooler when under direct sunlight. Visual analysis showed an elimination or reduction in the use of blinds and shades and more natural daylight within the offices.

Overall, the installation was completed in a timely manner and on budget. All performance objectives were met, and the host site has been staff and visitors have been enthusiastic and pleased with the impact on comfort in their building. This project has also created awareness and, most importantly, confidence with installing dynamic glass across many DOD installations. Several other high-ranking officials have visited the site and been exposed to this novel dynamic glass system.

1.0 INTRODUCTION

1.1 OBJECTIVE OF THE DEMONSTRATION

In an earlier ESTCP demonstration project (EW-201252), the project team installed replacement electrochromic glass (also termed dynamic glass) windows in a small office building. The project was able to demonstrate HVAC energy savings, lighting energy savings, and user preference for dynamic glass over traditional systems. However, the demolition of the existing windows and their replacement with dynamic glass windows was both costly and disruptive to the occupants. For those reasons, dynamic glass' applicability of the existing DOD building stock is limited to those requiring deep renovation or energy efficiency upgrades.

For those reasons goal of this project was to develop a new installation method to address those cost and disruption barriers. The project team developed a non-structural insulated glass unit, a 'dynamic in-fill' unit, and proposed to install and monitor its performance in an operational setting with reduced cost and minimal impact on the occupants.

Specifically, the project aimed to validate the performance and lifecycle cost benefits of a dynamic window system with a 50% lower installed cost. It was also anticipated that the installation and deployment exercise would also generate the data and insights needed to create awareness and acceptance of the technology. The project was intended to facilitate future technology transfer across all DOD building-stock, while providing a direct benefit to our host base in terms of reduced energy consumption, reduced lifecycle cost, and improved occupant comfort. The intended outcomes of this demonstration were twofold: first, the deployment of a 50% lower cost dynamic glass installation method compatible for use in a broad range of existing and 'historic' buildings. Second, the project aimed to validate the performance, comfort, and lifecycle cost benefits of dynamic windows in an operational environment.

The project team accomplished these goals by pursuing the following project deliverables: Installation of dynamic windows behind the existing glass in an operational demonstration site; modeling and monitoring of the energy consumption, peak-load and occupant comfort for both treated and untreated spaces; calculation lifecycle energy savings (energy, GHG) for the site; and quantification of the life cycle cost.

To accelerate the transfer of dynamic windows technology to the DOD, the project team also engaged with major DOD Energy Service Companies, including Johnson Controls (JCI) and Noresco, to enable and accelerate future installation through Energy Savings Performance Contracts (ESPCs). Our collaboration with these companies in concert with this demonstration project will allow Federal agencies to implement dynamic windows without upfront capital costs and without the need for special Congressional appropriations.

1.2 REGULATORY DRIVERS

Two important federal mandates are addressed by this technology:

1.2.1 Executive Order 13693

Planning for Federal Sustainability in the Next Decade proposes to cut the Federal Government's greenhouse gas emissions 40 percent over the next decade from 2008 levels and increase the share of electricity the Federal Government consumes from renewable sources to 30 percent. The Executive Order outlines a number of measures to make the Federal Government's operations more sustainable. By participating in the Federal Green Challenge, facilities are provided with technical support, networking opportunities, and tools to assist with tracking progress toward the Executive Order directives.

1.2.2 Sustainability Rule for Procurement⁵ under the Federal Acquisition Regulations (FARs)

The DOD, the GSA, and NASA recently issued a joint interim rule that requires all new construction to reduce energy use by 30% compared to the existing standard. For major renovations, buildings must reduce their energy use by 20% below their 2003 pre-renovation baseline. The new rule also requires increased use of natural daylight in all new and renovated buildings. Previous Research programs and studies by the Department of Energy Building Technology Program and Lawrence Berkeley National Labs indicate that dynamic glass may be a valuable solution to address these federal regulations. For example, their work indicates that dynamic glass can reduce building cooling loads by more than 10% while also allowing more daylight into the workplace, additionally reducing lighting energy costs^{6, 7, 8}.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

2.1.1 Technology Description:

Electrochromic glass is a window material that darkens when a voltage is applied to the glass. This darkening of the glass reduces the transmission of visible and infrared sunlight. When this glass is used in a typical doubled paned window it helps to reduce the heat load in a building that comes from solar irradiance.

The electrochromic device, applied to a single glass surface, is formed via a stack of five (5) thin coatings applied to the inner surface of the outer pane of glass in an IGU. To darken the window, low voltage direct current (<5V) is applied, driving ions from one layer of the coating to the next, causing the stack to change tint and also to absorb light and heat. Reversing the voltage reverses the flow of ions. This also reverses the effect and transitions the stack back to a clear state⁹.

By controlling the voltage, a dynamic glass glazing assembly can vary its Solar Heat Gain Coefficient (SHGC) from 0.46 to 0.09. This indicates that the transmitted radiant solar heat varies between approximately 46% of the incident solar radiation to about 9% of the incident solar radiation. Likewise, the electrochromic device can vary its visible light transmission from 58% transmission to just 3% total light transmission. In addition, intermediate tint states can be selected to optimize performance of the windows throughout the day.

Figure 1 (below) plots the transmitted light levels across the visible and non-visible spectrum for several common glazing products. Solarban and Solarban 70XL are the commercial names for very common low-e glass products from the PPG glass company^{10, 11}. They represent typical performance curves for the general class of low-e glass materials. The performance curves for View dynamic glass are given for the four available tint states. It can be observed that the infrared spectrum, representing about 50% of the sun's transmitted heat) is significantly attenuated by dynamic glass in Tints 2, 3, and 4.

All of the relevant insulated glass performance parameters can be found in Table 1.

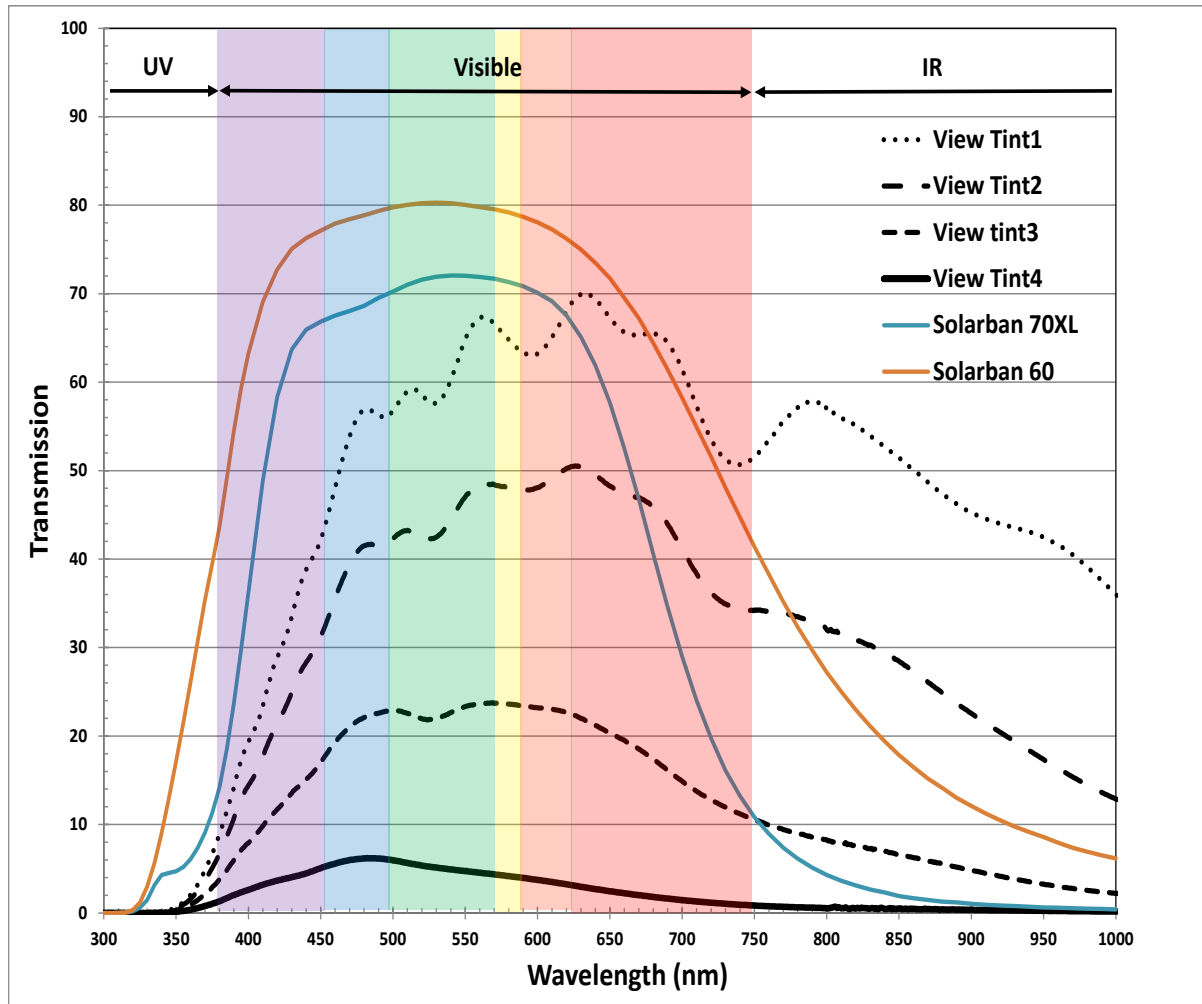


Figure 1. Electrochromic Window Configuration and Optical Characteristics Plotted against Low-e Glass Examples

Table 1. View Dynamic Window Performance Characteristics (including intermediate states).¹²

Tint Level	Transmittance (%)			Reflectance (%)			U-value	SHGC
	Visible	UV	Solar	Visible Out	Visible In	Solar Out		
Tint 1	58	3	37	18	20	18	0.29	0.46
Tint 2	40	2	21	12	19	12	0.29	0.26
Tint 3	20	1	8	8	17	11	0.29	0.16
Tint 4	3	0	1	7	17	11	0.29	0.09

For commercial installation and use, the electrochromic coated glass is packaged as a traditional insulated glass unit (IGU) for use in windows.

IGUs are sealed combinations of two or more lites of glass separated by a hermetically sealed space. A spacer is used to separate the lites. There is a primary seal between the spacer and the lites; this forms the hermetical seal. View uses a traditional industry best practices including a Polyisobutane (PIB) adhesive for the primary seal. The gap from the spacer to the edge of the glass is filled with the secondary seal. For this seal, View uses a silicone rubber structural material. View fills the hermetically sealed space between the lites with 90% Argon gas. These

IGUs are shipped to customers to be installed directly into the facade framing (in the case of large commercial building) or they can be mounted in a unitized element for installation later as in mid- or high-rise commercial office building applications.

Figure 2 illustrates how the visible light transmission and the solar heat gain are reduced as the glass darkens.

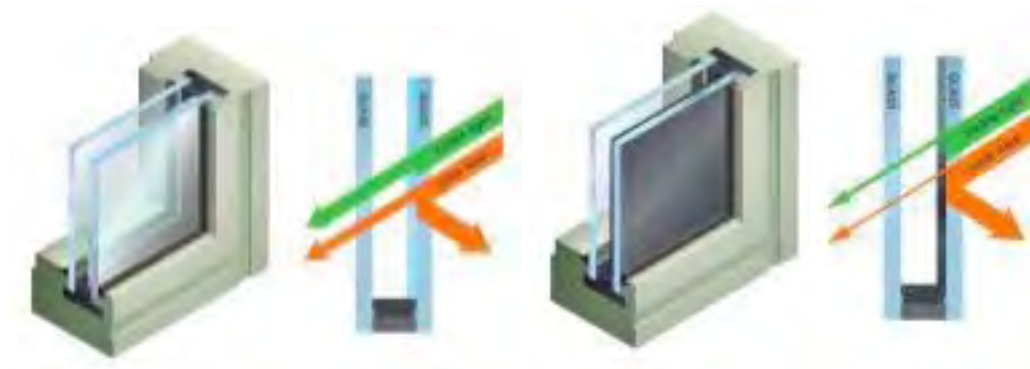


Figure 2. Cutaway View of an Electrochromic Window in the “Tint 1 - Clear” (left) and “Tint 4 - Dark” (right) states.

This commercially available IGU is also suitable for major renovations where the façade will be reconstructed with new glazing and possibly frames. For renovation projects where the existing glass is not being replaced, an alternate solution needs to be developed.

2.1.2 Energy Consumption:

Total energy consumption by these windows is negligible (1800 sqft of glass uses less power than a 60W light bulb). All energy calculations in this proposal include this small energy consumption.

2.1.3 Impact on LEED and ASHRAE Requirements:

Use of dynamic glass is explicitly recognized and accepted by the current ASHRAE Standards. ASHRAE 90.1 – 2013 describes the specific treatment of dynamic glass in determining project compliance either by the prescriptive or performance paths. With technology/product acceptance ensured, dynamic glass is a preferred project component based upon its energy performance and code required savings objectives. When used in a new construction or renovation project, it can have a beneficial energy impact of 5-20% total building energy savings. That incremental savings can be crucial to making a project compliant with the current standard.

Beyond minimum code requirements, the use of dynamic glass can often offset other capital-intensive building elements required for high performance or LEED certified design, as required for federal new construction and deep renovations. As an example, the promotion of ample daylighting (75% of floor area)¹³ drives larger window area and often requires the use of expensive external shades, louvers or light shelves. Or, in the case of hospital settings, operable shades are often encapsulated within the insulated glass unit to minimize the chance of infection prone materials. Dynamic glass eliminates these measures with a single solid state solution delivered at a lower net first cost.

2.1.4 Antiterrorism Standards:

Dynamic glass technology is compliant with UFC-4-010-01. Specifically, the completed ESTCP project demonstrated compliance with UFC directives including “DoD Minimum Antiterrorism Standards for Buildings” (4-010-02) and to the updated requirements applying to “New Construction” and “Existing Buildings”. Also, there are currently four CCRs that have been submitted with regard to the use of chromogenic (dynamic glass). These include:

- UFGS 08 51 13 Aluminum Windows (CCR submitted 2014-07-09 17:06 UTC)
- UFGS 08 60 45 Skylights and Translucent Panels (CCR submitted 2014-07-09 17:22 UTC)
- UFGS 08 81 00 Glazing (CCR submitted 2014-07-09 17:38 UTC)
- UFC 3-101-01 Architecture (CCR submitted 2014-07-24 19:33 UTC)

Third-party certification of View Dynamic Glass windows was completed as part of this project, and can be found in the prior ESTCP project report.

2.2 TECHNOLOGY DEVELOPMENT

This demonstration project is the first full-scale deployment of the dynamic glass technology packaged in a form factor designed to be compatible with buildings that keep their existing glass in place. Termed a Dynamic In-Fill product, it sits inside the existing building envelope in the existing window pocket. Figure 3 below shows a cross section of building envelope with the addition of the Dynamic In-Fill product. As shown in Figure 3A, the electrochromic device is applied to the inner surface of the outer pane of glass in the double-pane IGU. This is then in-set and securely mounted to the existing window frame system. The system is designed to prevent condensation by allowing a small amount of air to circulate between the IGU and the original window pane.

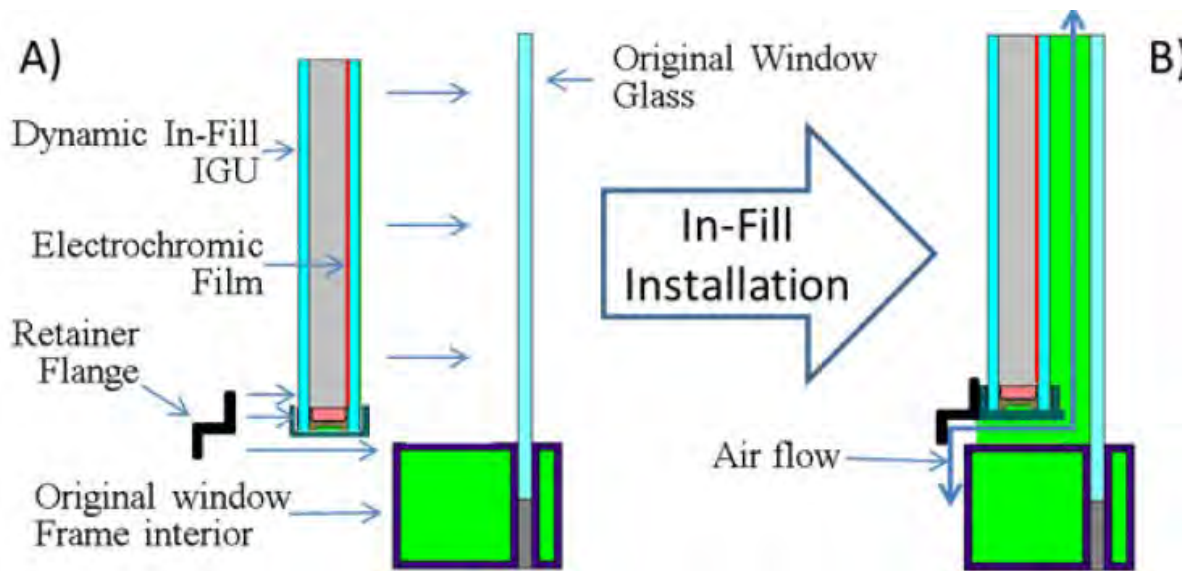


Figure 3. Dynamic In-Fill Product.

Figure 3A – prior to installation, the infill component is sized to the available window. Figure 3B – the complete system showing the proximity of the surfaces and designed venting path.

2.2.1 Applications of the Technology:

This technology is applicable to virtually all of the existing DOD building stock, specifically cost effective envelope retrofits for the thousands of buildings that currently feature aging, inefficient windows. This technology is particularly high-value in deep renovation situations, where the windows and HVAC systems are already slated for replacement/upgrade. In those situations, the enabled capital avoidance of refreshed HVAC systems can often completely offset the increased cost of the dynamic windows, generating all of the benefits demonstrated here at no net additional cost. This technology has already generated enthusiasm among the DOD installation energy managers who were approached during this project, and who visited our host-site to see the technology in action.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Alternative Technologies:

Windows technology today represents a compromise of the DOD's competing of energy efficiency and workplace performance. Clear double pane insulated glass units (IGUs) provide thermal insulation and natural lighting, reducing interior heating and artificial lighting. However, these IGUs allow significant unwanted solar heat-gain to enter the building, increasing the size and consumption of HVAC systems due to a higher cooling load. Tinted and reflective IGUs provide thermal insulation and block solar heat-gain, reducing cooling and heating, but they also block natural light, increasing lighting requirements inside. Modern low-emissivity ("low-e") IGUs attempt to balance these extremes by blocking some solar heat-gain while allowing for natural light to pass. However, they are still a compromise striking a single performance value for both summer and winter conditions for the life of the product.

This leads to significant annual lighting and heating energy consumption. Further, these static low-e IGUs do not control glare, therefore requiring the use of blinds and limiting the use of daylighting. Typical practice leads to blinds that are often left in the closed position all day, significantly exacerbating lighting energy consumption beyond what building managers intend or budget for. Dynamic glass is a technical response to these issues. It has been designed to maximize daylight, energy efficiency, and comfort in response to the outdoor conditions.

2.3.2 Advantages and Limitations of Dynamic Windows Compared to Low-E Windows:

Advantages: There are significant benefits of dynamic glass compared to low-e windows:

- 1) *Cuts Solar Heat by 75% in the Summer:* Dynamic glass has a SHGC that can be tuned as low as 0.09 in the summer compared to 0.38 for a typical static low-e window, dynamic windows can cut solar heat gain by approximately 75%, thereby reducing the cooling load on peak days and throughout the cooling season. For installations with older generation clear glass, the current SHGC may be as high as 0.60, allowing for greater potential savings.
- 2) *Increases Solar Heat by 33% in the Winter:* With a SHGC that can be tuned as high as 0.46 (versus the 0.38 for typical low-e glass), dynamic windows can allow 33% more passive solar heating than static low-e, reducing heating load in the winter.
- 3) *Reduces whole-building peak-load versus low-e:* Replacing existing clear glass with low-e glass can reduce a buildings peak load by approximately 20%. Use of dynamic glass can double this benefit to a 20+% peak load reduction. This peak load reduction can result in smaller, less expensive replacement HVAC systems during renovation cycles.
- 4) *Reduces Transmitted Light by 95%:* With a visible light transmittance (T_{vis}) that can be tuned as low as 3%, dynamic windows can reduce the incoming light by 95% below low-e ($T_{vis} \sim 70\%$). This light mitigation can prevent glare and visual discomfort in a variety of working environments. It also has the secondary benefit of improving occupant comfort without compromising outdoor views lost via the use of shades or blinds associated with blinds and shades.
- 5) *Significantly Improves Daylighting:* With shade free operation and T_{vis} that can be tuned as high as 58%, dynamic windows can allow for higher average daylight use throughout the day over low-e with blinds, thereby reducing artificial lighting energy. Analysis of multiple office building in various settings has revealed that typical natural light levels are 2-3 times higher (a 100-200% increase) for workspaces with dynamic glass versus blinds and shades.
- 6) *Greater Lifecycle Cost Savings:* Through a combination of reduced energy consumption and reduced capital and maintenance costs, the total lifecycle cost savings can be up to 300% higher than those realized with low-e in an equivalent building.

Limitations: The limitations of dynamic windows compared to low-e are minor and have been minimized through an engineering approach that reduces materials and labor required for installation:

- 1) *Higher Up-Front Cost:* The installed cost of dynamic windows is 50% higher than a comparable low-e system. However, this cost is easily offset by the reduction in HVAC capital expense (CAPEX), elimination of replacement blinds and their maintenance, and lifetime energy savings. For many installations, dynamic windows can be installed with a net cost at or below the cost of renovation with traditional low-e windows.
- 2) *Slightly More Complicated Installation:* Dynamic windows require low-voltage wiring and control systems, but do not require a licensed high-voltage electrician for installation. This wiring is akin to installing data network or alarm cables in the building and can be achieved at costs of \$2 - \$5 per square foot of window area.
- 3) *Single pane size limitation of 5 ft by 10 ft* – Today, maximum dynamic glass dimensions are 5 ft by 10 ft. While traditional glass can be produced in larger formats, the 5 ft x 10 ft max size addresses 90% of the existing glass market. It also represents nearly 100% of the existing DOD building stock.

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3.0 PERFORMANCE OBJECTIVES

The Performance Objectives (POs) for this project directly relate to energy security, cost-avoidance, GHG emissions and occupant comfort. They were generated based on the direct measure of the impact of dynamic windows on a previous small pilot installation. This demonstration project successfully achieved all Performance Objectives.

3.1 TABULAR SUMMARY OF PERFORMANCE OBJECTIVES

Table 2. Summary of Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Annual HVAC/Lighting Energy Usage	Energy Intensity (kWh/ft ²)	Sub meter readings, demonstration and control zones	>15% annual energy saving over existing
Building Peak Load	Peak Power Intensity (kWh/ft ²)	Peak meter readings, demonstration and control zones	>25% peak energy reduction over existing
Lifecycle GHG emissions	Metric tons CO ₂ via complete LCA	3 case energy models	>24% savings over existing
Life Cycle cost	Dollars spent	Calculations of installation cost, cap., & maint. savings	2x savings over dynamic glass replacement
Qualitative Performance Objectives			
Occupant Comfort	Likert-type survey results plus real time data	Real-time feedback from users	Statistically significant gains in comfort
User Awareness and Acceptance	Survey results and reactions	Direct feedback from users and facility staff	Statistically significant gains in satisfaction

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4.0 FACILITY/SITE DESCRIPTION

The host-site for this project was Roosevelt Hall at Ft. McNair in Washington DC. This site was selected due to:

1. Its high visibility within a broad range of experienced and geographically diverse Army personnel (Roosevelt Hall houses the National Defense University)
2. Its location on the east coast. The site is therefore able to provide performance data from a very different climate (ASHRAE Climate Zone 4¹⁴) than View's original ESTCP demonstration project at MCAS Miramar, CA (ASHRAE Climate Zone 3).
3. A mixed hot/cold climate with high humidity, representing the most challenging environment to address condensation concerns for Dynamic In-Fill windows. The goal of this constraint was to establish that if the project had a positive result re condensation, it would validate viability of this approach at most DOD bases.
4. The project demonstration site is also a heritage building, allowing us to demonstrate that an In-Fill retrofit can be accomplished without changing any aspect of the exterior façade, enabling the technology to be deployed across the broadest range of DOD buildings.

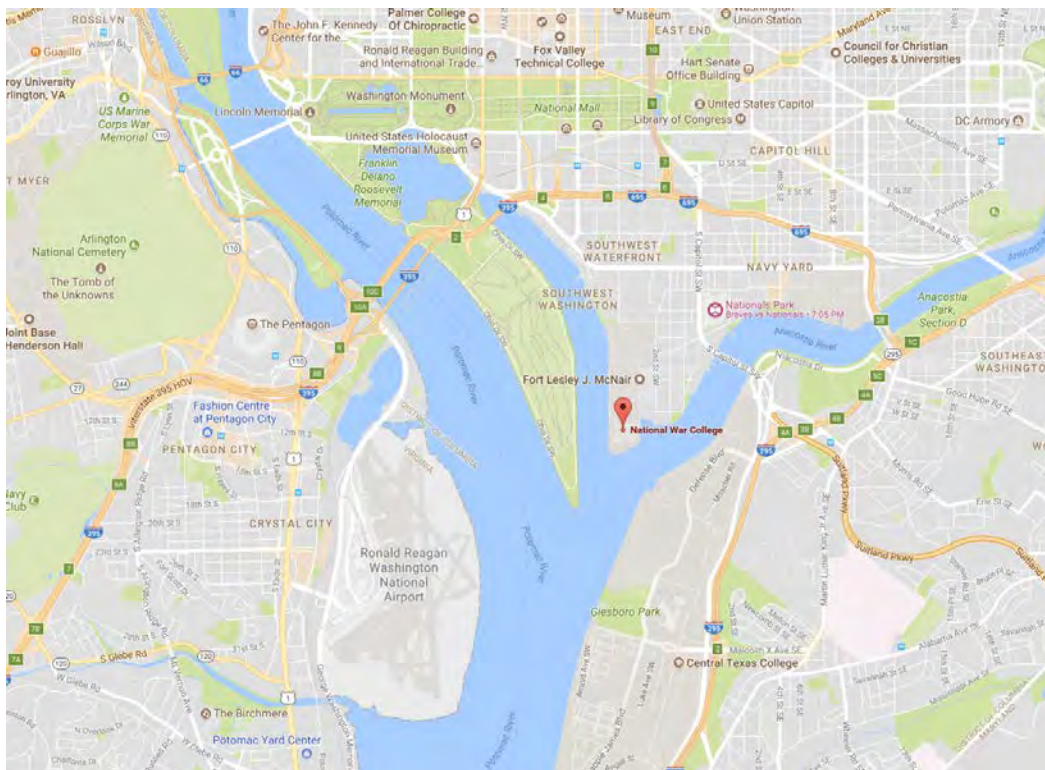


Figure 4. Location of Roosevelt Hall on a Washington DC Area Map

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The National War College of the United States is a school in the National Defense University. It is located in Theodore Roosevelt Hall on Fort Lesley J. McNair, the oldest active Army Post in existence today. The building was constructed in 1903 with high-mass brick construction. It is designated as a National Historical Landmark (1972) and listed on the National Register of Historic Places (1972)¹⁵.



Figure 5. Roosevelt Hall, National War College, Washington DC

The project scope was to install the Dynamic In-Fill product on the South façade of the building's second floor to replace the existing single-pane clear glass. Image below shows the second floor of Theodore Roosevelt Hall marked with the Dynamic In-Fill installed locations.

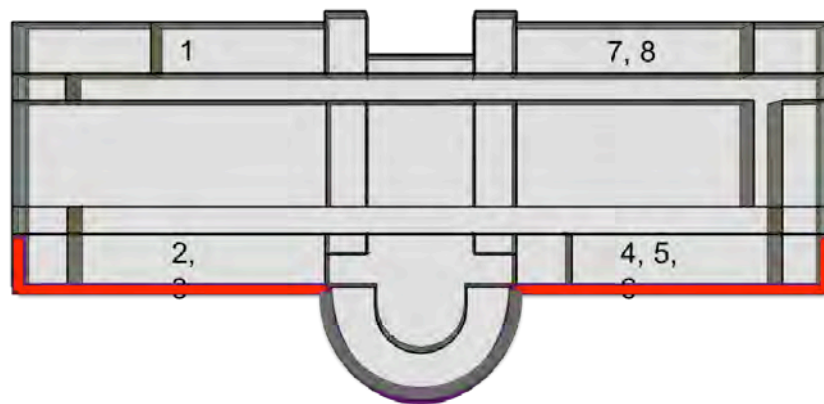


Figure 6. View Glass Locations Marked in Red

In total there were 58 individual dynamic in-fill units installed totaling approximately 1,500 sq ft of glazing.

4.2 FACILITY/SITE CONDITION

Although the building's brick façade was original, the windows had been replaced within the last 30 years as part of a modernization and energy efficiency renovation. The original windows had been operable, true divided-lite single pane windows with steel or wooden window frames. The term divided lite refers to windows where each pane within a window (the small square or rectangular elements) are each an individual piece of glass separated from each other. In order to accommodate insulated glass, modern windows have moved away from divided lite in favor of continuous glass single pane or simulated divided lite (accomplished with faux dividers either on the glass surface or between the IGU lites)¹⁶. Dynamic In-Fill renovation to those original windows would have been impossible due to incompatibility of the frames (there would be latches, hinges, and other operators at the perimeter of the windows that would foul the In-Fill IGU) and due to the anticipated high air and moisture leakage of the operable design.

The replacement windows were those typically found in 20-50 year old buildings. The windows were fixed (inoperable) with frames consisting of square or rectangular profile aluminum extrusions. The extruded aluminum frames has a standard bronze anodized finish.

Unlike contemporary commercial windows, these replacement windows were designed and fitted with single pane glass (today's windows would use a dual pane IGU). Following their installation into the façade, the windows were again renovated with a low-e film applied to the inner surface of the glass. Low-e films such as these are meant to shave some energy, but do little to mitigate excessive glare or thermal comfort. Additionally, the persistence of a single glass pane design continues to allow for cold (uncomfortable) window surfaces regardless of the surface film applied.

The Figures below show the existing conditions of the glass and framing for the project site.



Figure 7. Single Pane Glazing at the Site, Pre-demonstration

In addition to the use of a solar control film on the glass, the site used extensive shading to control glare and temperature. In fact, all of the south facing windows were fitted with both 'blackout' roller shades and horizontal blinds. Figure 9 shows examples of the blackout shades with the horizontal blinds retracted, whereas Figure 10 shows a typical south facing conference/classroom with the horizontal blinds partially deployed.



Figure 8. Dual Blind Treatments Typical of all Existing Windows



Figure 9. Typical South Facing Classroom / Conference Room

The final pre-installation figure is one of a private office on the southwestern corner of the building. It illustrates that the south facing windows are fully shaded to prevent glare while simultaneously, the west windows are kept unshaded to allow ambient sunlight to penetrate. This illustration shows the preferred mode of operation for the facility - southern windows covered, east, west, and north windows uncovered.



Figure 10. Private Office with South and West Facing Facades

4.3 SITE-RELATED PERMITS AND REGULATIONS

Regulations - The demonstration project planning and implementation followed US Army Corps of Engineers *Safety and Health Requirements Manual* EM-385-1-1¹⁷. Associated with the safety and health requirements, the project used an Accident Prevention Plan (APP), an Activity Hazard Analysis (AHA), a Quality Control Plan (QCP) and Quality Control Management to the Resident Officer In Charge of Construction (ROICC) office for review and approval prior to project initiation. The project team also identified all personnel trained to Federal OSHA protocol and submitted their names in to the facility manager.

The project design and implementation was in accordance with all relevant facility regulations. Specifically, the exterior window components and their controls will follow the guidance of the Unified Facilities Criteria: Administration Facilities, UFC 4-610-01.

Optimization of natural light (daylighting) – The demonstration project complied with UFC 3-530-01. The LEED green rating system is a consideration of UFC 3-530-01 and as considered as a complementary design requirement for the project.

Anti-terrorism – The applicable elements of the demonstration project complied with UFC 4-010-01, DOD Minimum Antiterrorism Standards for Buildings and UFC 4-020-01, DOD Security Engineering Facilities Planning Manual.

Barrier-Free Design – The replacement façade was designed and implemented to be barrier-free and accessible in compliance with the Architectural Barriers Act (Public Law 90-480) and in accordance with the Uniform Federal Accessibility Standards (UFAS), published as FED-STD-795, and 28 CFR Part 36, the Americans With Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG).

Design Criteria – Referenced standards utilized for the framing system included:

- Department of Defense Minimum Antiterrorism Standards for Buildings, UFC-4-010-01, Department of Defense, 08 October 2003 (including change 1, 22 January 2003).
- Department of Defense Minimum Antiterrorism Standoff Distances for Buildings, UFC 4-010-02, Department of Defense, 08 October 2003 (including change 1, 19 January 2007).
- ASTM F2248-09 Standard Practice for Specifying an Equivalent 3 Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass.
- ASTM E1300-12a Standard Practice for Determining Load Resistance of Glass in Buildings.
- “Metal Curtainwall Fasteners”, American Architectural Manufacturers Association, Report AAMA TIR A9-91, 1991.

Additional submittal documents were required. These included:

- A Site Logistics plan, including plans for material staging, parking, lunch areas, approved bathrooms, work hours, phased construction plan
- Product data sheet and full shop drawings for the window components. These shop drawings were provided were hard and soft copies on the NAVFAC template.
- Electrical cable interconnect drawings
- Activity Hazard Analysis Documents complying with US Army Corps of Engineering EM385-1-1 Safety and Health requirements.

5.0 TEST DESIGN

5.1 FUNDAMENTAL PROBLEM:

The project goal is to address the issue of inefficient windows in buildings, one of the most significant components impacting building energy efficiency for the military today. Traditional windows allow unwanted solar heat to enter, increasing the need for cooling energy in the summer, and also producing glare. Glare degrades occupant comfort and results in the overuse of blinds, eliminating views to the outdoors and unnecessarily increasing the need for electrical lighting. Electrochromic windows are able to address these problems by blocking solar heat gain while still allowing for natural light to enter, thereby reducing energy use, greenhouse gas emissions, and unwanted glare.

5.2 DEMONSTRATION QUESTION:

This demonstration sought to solve several related problems by answering the following questions:

- 1) Can dynamic in-fill windows be installed into an occupied office building without a significant disruption to the occupants?
- 2) What is the total energy savings from HVAC and lighting usage as a result of installing dynamic windows?
- 3) What is the impact of dynamic windows on the building's peak power consumption and total energy usage?
- 4) What was the reduction in lifecycle GHG emissions as a result of these energy savings?
- 5) What as the total cost savings attributable to dynamic windows over their operable lifetime?
- 6) What is the quantifiable improvement in occupant comfort and satisfaction due to reduced glare and improved visibility?

5.3 TEST DESIGN

5.3.1 Experimental Design:

The goal of this project is to demonstrate that dynamic in-fill can provide the same performance benefits as traditional dynamic window retrofits, but at dramatically lower cost, and with minimal operational disruptions. We will demonstrate this new product in an operational environment at a DOD facility at sufficient scale to validate its performance and cost benefits for future DOD deployment as well as validate the minimally disruptive nature of the installation process. To accomplish this, we collected both quantitative and qualitative data addressing each of the key Project Objectives.

- 1) Install Dynamic In-Fill, in collaboration with a federal ESCO, in an operational DOD facility, with minimal occupant disruption
- 2) Monitor HVAC and lighting energy consumption, as well as occupant comfort, for a period of 12 months before and 12 months after installation of Dynamic In-Fill windows;

- 3) Quantify the energy-, cost-, peak-load- and GHG- savings, the payback and savings/investment ratio for Dynamic In-Fill, and quantify the capital equipment savings enabled for future HVAC upgrades;
- 4) Create ECM definitions and metrics for Dynamic In-Fill and work with ESCOs to integrate them into their ESPC ECM portfolios; launch first ESPC-financed Dynamic In-Fill project;
- 5) Using an experimentally validated energy model, estimate total cost, energy and GHG savings potential across DOD's building stock (with consideration for relevant metrics such as building type and climate zone);
- 6) Engage DOD users to understand and meet acceptance requirements for Dynamic In-Fill (including regulatory requirements), create awareness and accelerate the adoption of Dynamic In-Fill.

5.4 BASELINE CHARACTERIZATION

5.4.1 Baseline Energy Models:

The goal of this study is to quantify and document the energy savings incurred by replacing the existing single-pane glass with high-performance Dynamic In-Fill glass. Due to the lack of measured historical energy consumption data, an energy calibration approach was adopted by following the steps below:

- Sub meters were installed on the entire second floor of the building to monitor electrical receptacle, lighting and HVAC energy at the panel level for a period of about two week when the floor experienced school-in-session occupancy.
- A calibrated energy model for the second floor was developed to match the two-week metered conditions (post-installation period of Dynamic In-Fill glass) in OpenStudio¹⁸. Additional information includes drawings provided by the college, and window control and modeling strategies provided by View. The baseline model (pre-installation period of Dynamic In-Fill glass) was then obtained by modifying the window properties of the calibrated model to match existing windows.
- A comparative analysis was conducted by comparing the energy consumption of the baseline model and the calibrated model for spaces that experienced the window retrofit to determine the energy savings from Dynamic In-Fill glass.

5.4.2 Energy model calibration:

In order to estimate the energy savings from installing View Dynamic Glass, an energy model representing the building operation after the window retrofit was developed and calibrated to measured data over a period of about two weeks. Constrained by the existing panel layout and HVAC thermal zone definition, it was very difficult to measure the energy usage only in spaces where the window retrofit took place. Taking into account the flexibility of parsing out the energy usage for the retrofitted spaces in the energy model, the scope for the on-site sub-metering as well as the calibrated model was expanded to the entire second floor. In developing the calibrated energy model for the case with View Dynamic Glass, the following steps were taken.

- Metered data was collected for the period of September 2, 2015 to September 16, 2015.
- An energy model (also referred to as the calibrated model) was built for the second floor of the National War College to match the construction and mechanical design as shown on the drawings provided by the college personnel.
- View Dynamic Glass was modeled in the calibrated model with an overall U-value (including framing effect) of 0.35 Btu/sf/hr/°F and two tint states, with its clear state having a Solar Heat Gain Coefficient (SHGC) of 0.28 and tint state 0.18. Under View's guidance, the glass was modeled to tint when the solar incidence level on the glass exceeded 25 Btu/sf/hr.
- The energy model's lighting and individual electrical receptacle energy were calibrated to match the metered data, completing the energy model calibration.

5.4.3 Energy model detailed description:

A 1-story building was modeled to represent the 2nd floor of the National War College building (floor plan shown in Figure 11 below). Its floor construction was defined as adiabatic to prevent heat transfer with the ground because in reality, the 2nd floor is not in direct contact with the ground and the vertical heat transfer between floors is minimal assuming all spaces are conditioned to similar temperature set-points.

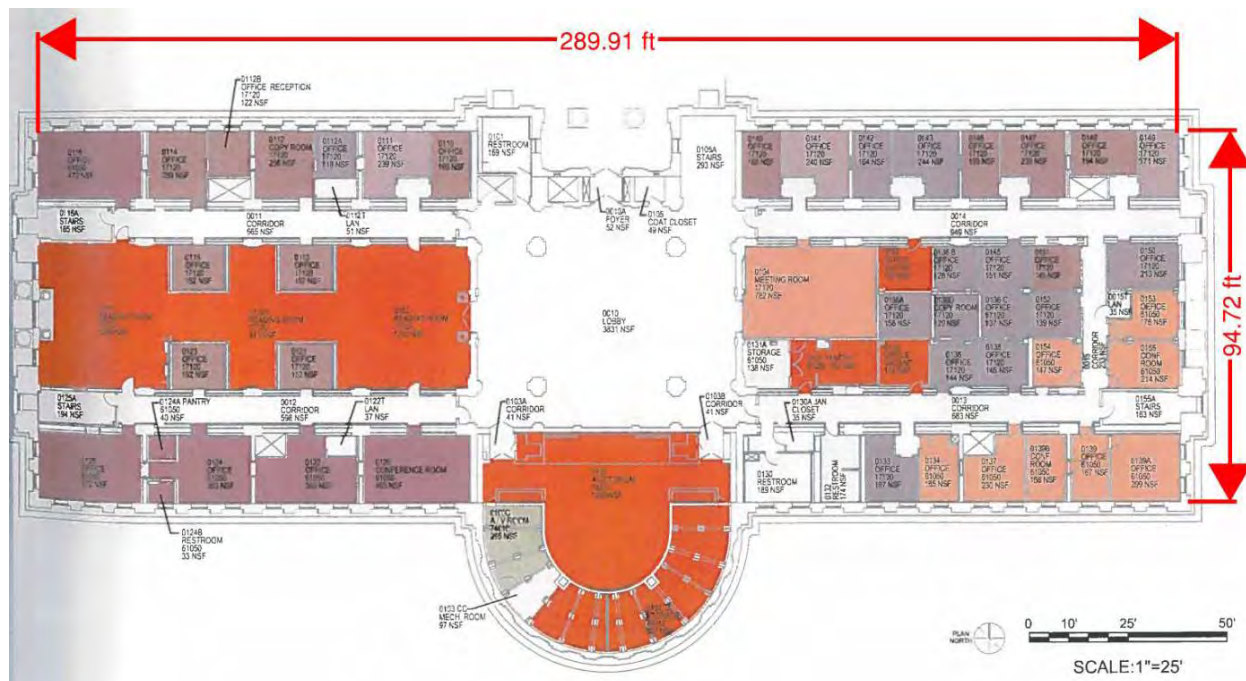


Figure 11. National War College, 2nd Floor Plan

Screenshots of the geometry of the energy model are shown in Figure 12. The window-to-wall ratio was estimated to be 40%. The primary HVAC system type for the site is fan coil units with dedicated outside air systems. A rooftop chiller and an electric resistant water heater supply chilled water and hot water respectively, to the fan coil units.

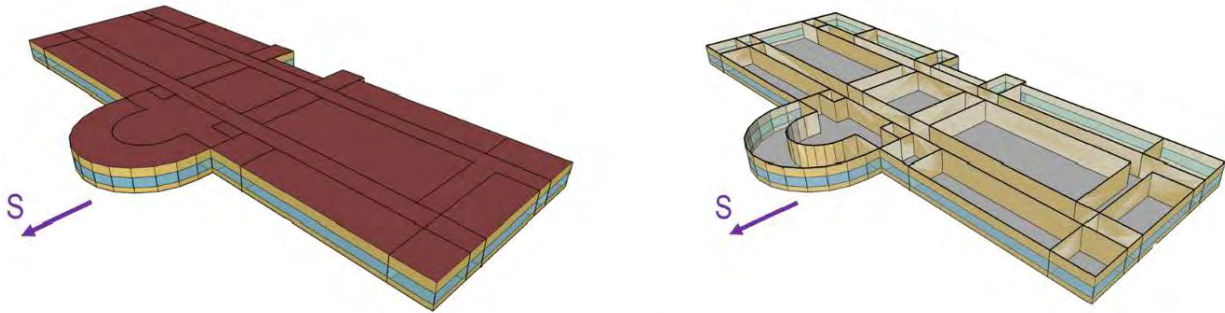


Figure 12. Baseline Energy Model, Created in the OpenStudio Software

5.4.4 Energy model calibration results:

The calibrated lighting and receptacle inputs are listed in Figure 13. Although the calibration was conducted for the whole 2nd floor model, shown below are only inputs for spaces that experienced the window retrofit because only these spaces are analyzed in the following energy performance assessment.

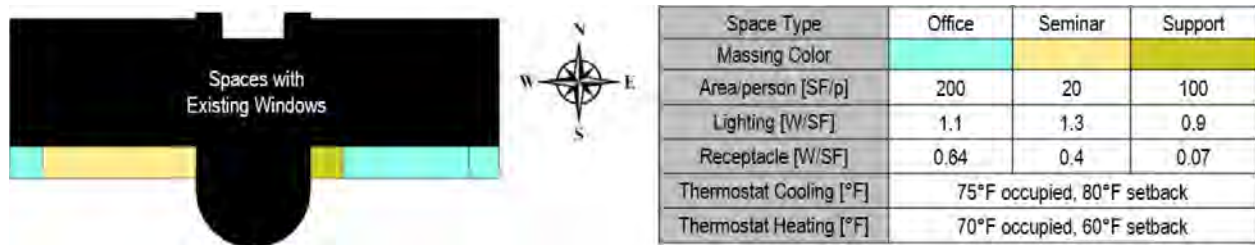


Figure 13. Calibrated Inputs for Space with View Dynamic Glass

Due to the limitation of the existing panel layout (Figure 14 and Table 3) in the building, the measured lighting energy and HVAC energy were combined in the collected data, which made it impractical to calibrate the lighting and HVAC energy separately.

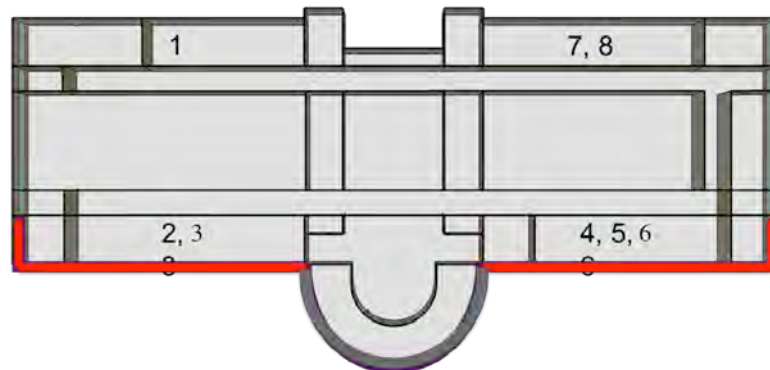


Figure 14. Calibration Panel Locations

Table 3. Corresponding Panel Identifiers and Load Type for Panel Locations Described in Figure 14

#	Panel	Location	Type	Load Type
1	RIN-2A2	NW	Hobo	Lighting or HVAC
2	RIN-2A1	SW	Hobo	Lighting or HVAC
3	CIN-2A1	SW	Dent	Plug Load
4	RIN-2B1	SE	Dent	Lighting or HVAC
5	RIN-2B1	SE	Hobo	Lighting or HVAC
6	CIN-2B1	SE	Hobo	Plug Load
7	R1N-2B2	NE	Dent	Lighting or HVAC
8	C1N-2B2	NE	Hobo	Plug Load

With reasonable assumptions of the mechanical equipment efficiencies and schedules (using data from similar building types and vintages in the DC area), the lighting power density was then adjusted to achieve similar combined energy consumption of HVAC and lighting as the measured data. The modeled receptacle energy matches up to the measured data within a reasonable error range (<4%).

Most important, the combined calibrated building energy model, one that considers HVAC, lighting, lighting, and all miscellaneous receptacle energy consumption was very well correlated to the actual usage. Modeled consumption was a 97% of actuals over a 1-year period. This is a superior correlation (<4% discrepancy).

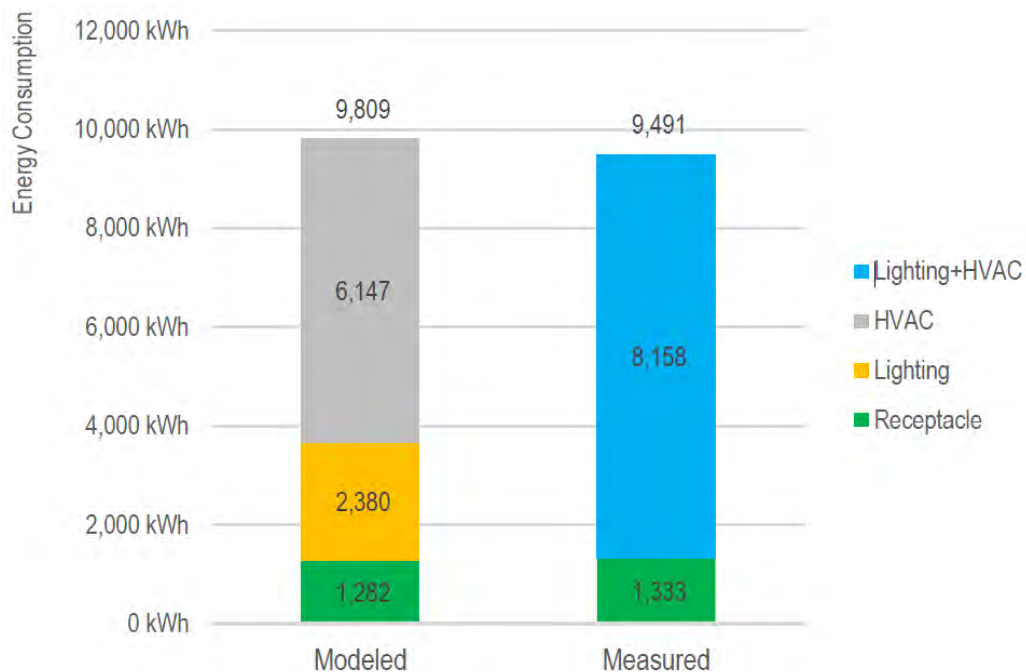


Figure 15. Energy Consumption for the Calibration Period of 9/2/2015 - 9/16/2015 (modeled vs measured)

5.5 DYNAMIC IN-FILL SYSTEM DESIGN AND INSTALLATION:

5.5.1 Preparation:

One major consideration for the project completion and success was the review and approval of the regional Historical Society. Following the submission of the proposal, including project photos and design drawings, by the National War College team, the project was given approval. Because the dynamic in-fill preserves the existing framing and glass of the exterior façade, it was deemed that the renovation would not diminish the historical significance of the building.

All windows within the project scope (2nd floor south, east, and west) were measured, and any special requirements beyond window and IGU parameters, were identified. An installation schedule was established with the facilities operations teams to coordinate installation between semesters and scheduled classes. As a result, all of the installation was completed in less than two weeks in December of 2014.

Balance of Systems installation:

The first step of Dynamic In-Fill installation does not involve the window units, but instead installation of the components of the wired network that controls the dynamic glass. Power and control cables of the IGU, termed drop cables were installed above the windows in the existing ceiling plenum created by a standard drop ceiling design. In addition to the installation of drop cables, window controllers (the electronic components used to regulate power transmission and send control signals to specific IGUs, were also mounted in the ceiling plenum. The figures below depict installation of these perimeter network components. An overview of the cable and window controller physical attributes and installation instructions¹⁹ can be found here: <http://viewglass.com/assets/pdfs/bos-cables-overview-guide.pdf>.



Figure 16. Available Space for Dynamic Glass System Components in the Existing Ceiling Plenum



Figure 17. Installation of Dynamic Glass System Components in the Existing Ceiling Plenum

Next, the central trunk cables were laid out in the central corridors in order to transmit power and information to the perimeter components. Similar to the drop cables and window controllers, these were installed into the existing ceiling plenum without disruption to the existing conditions in the ceiling or occupied spaces. An overview of the trunk cable physical attributes and installation instructions can be found here: <http://viewglass.com/assets/pdfs/trunk-line-installation-guide.pdf>.



Figure 18. Installation of Dynamic Glass System Components in the Existing Ceiling Plenum

For the View dynamic glass system, power and logic are delivered via a centrally located control panel. This unit is a single cabinet with dimensions of 20 inches by 26 inches by 9 inches deep. The control panel was located in the existing 2nd floor electrical closet (adjacent to the fire alarm system control panel). An overview of the control panel physical attributes and installation instructions can be found here: <http://viewglass.com/assets/pdfs/control-panel-installation-guide.pdf>



Figure 19. Control Panel (with Power Supply and Network Controller) Installed

Dynamic In-Fill installation:

Dynamic IGUs were fabricated by View, including 6mm middle and interior glass, and integrated into fixed Aluminum windows designed for a flush fit with the existing windows. The final configuration of the existing window and the Dynamic In-Fill is shown below.

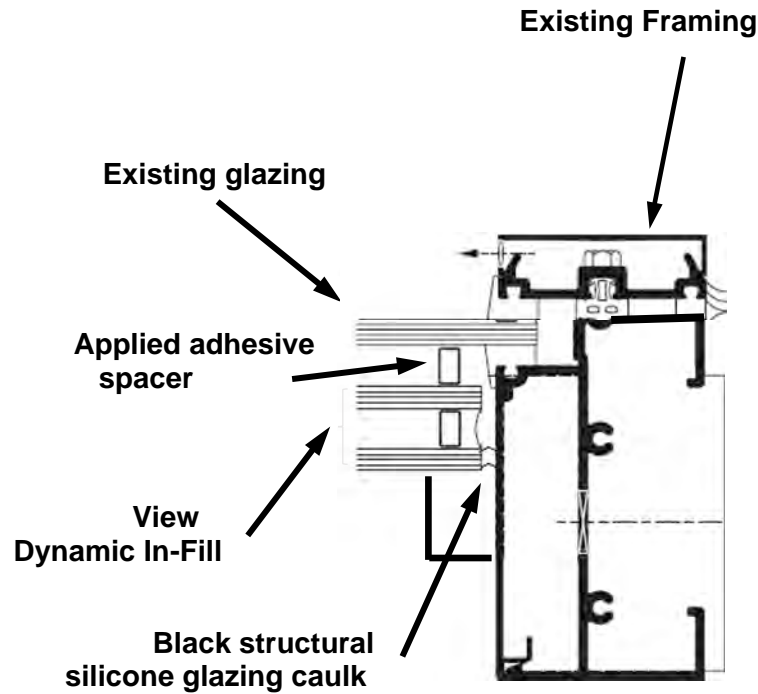


Figure 20. Configuration of a Typical Dynamic In-Fill Unit

Completed Dynamic In-Fill units were delivered to the site for installation via a multistep process. Installation was conducted in a fully operational facility. The only requirement was that the room in which Dynamic In-Fill installation was occurring be unoccupied at the time. As a result, installation was conducted across the entire project site during a single break in the class schedule between teaching semesters.

The first step for Dynamic In-Fill installation was to mount a perimeter spacer to a dynamic glass IGU. The surface of the glass was cleaned and prepped prior to spacer installation (see Figure 21 below).



Figure 21. Perimeter Spacer / Seal was Applied at Site

Next, a vacuum pump is situated to create a vacuum adjacent to the existing glass for a given window unit. The seal-prepped IGU is placed into the existing window pocket with the vacuum pump in place. The IGU is pressed to create a tight seal with the existing glass. Once the IGU is settled into a stable position, the vacuum pump is engaged to evacuate the cavity between the existing glass unit and the Dynamic In-Fill unit. This step in the process removes air, moisture, and any foreign material.

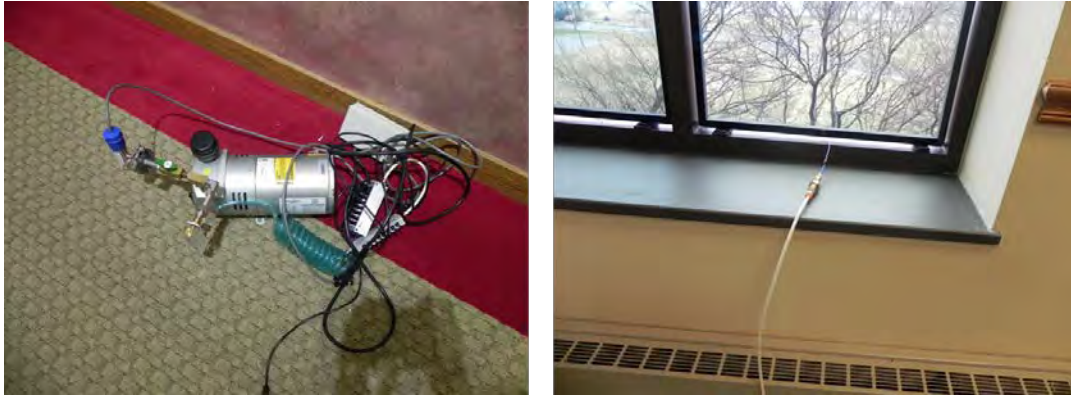


Figure 22. Desiccated Vacuum Seal is Created

Once the air cavity between the existing glass and the Dynamic In-Fill unit was drawn down to a low-density, low moisture condition, the port for the vacuum was withdrawn and the seal fully closed. The Dynamic In-Fill unit is stable – held in place by both negative air pressure and by the adhesive in the external perimeter seal.

The installed unit is then finished with a perimeter of rectangular profile aluminum framing with a finish matching the existing frame. In the case of the demonstration project, all frame finished are a traditional architectural ‘bronze’ finish. Figures 23 through Figure 25 below show the finished retrofitted windows.

This process was repeated for all 58 window units within the project scope.

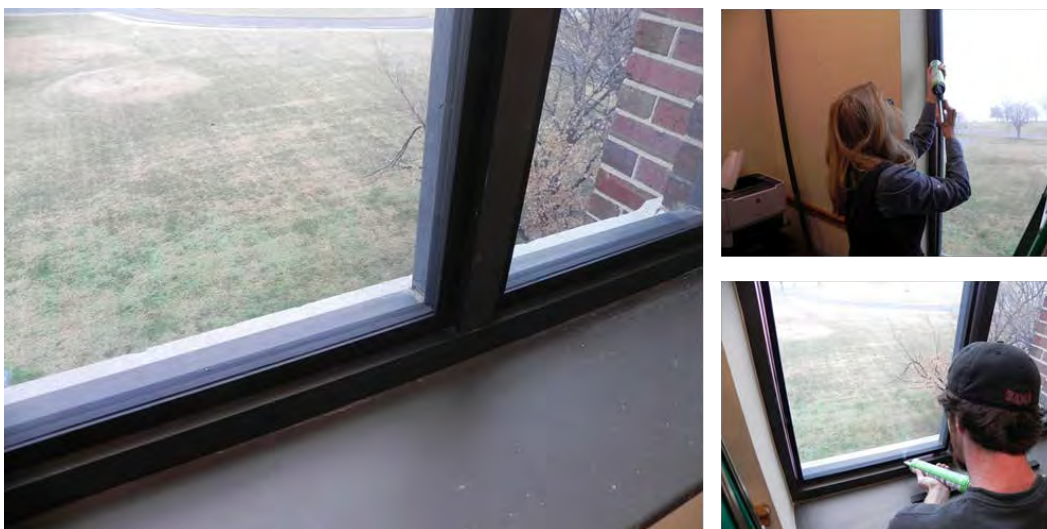


Figure 23. Interior Frame Being Installed and Sealed



Figure 24. Glass Appearance as Commissioned – During Tint Transitioning



Figure 25. Glass Appearance as Commissioned – Fully Tinted

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6.0 PERFORMANCE ASSESSMENT

6.1 TOTAL BUILDING ENERGY IMPACT

A baseline model was created by modifying the calibrated model described in the earlier sections. In all non-glass aspects (physical design, system components, operational conditions) the baseline model were held constant to the calibrated model. The only difference between the two calibrated models was that for the baseline View Dynamic Glass was replaced with a window construction reflected that of the previously existing glass. The baseline glass was given the performance parameters of an overall U-value of 0.53 and an SHGC of 0.53 consistent with the approximate performance of the existing glass.

Both the baseline model and the calibrated model were then simulated for the whole year using the TMY3 weather data for Washington, DC. The energy consumption data for office spaces and classrooms that were within the scope of the demonstration projects (those with the Dynamic In-Fill retrofit) were extracted from both models and compared against each other to quantify the savings from installing the Dynamic In-Fill system. Figure 26 shows the estimated monthly and annual energy savings from the recent installation of View Dynamic Glass in the National War College.

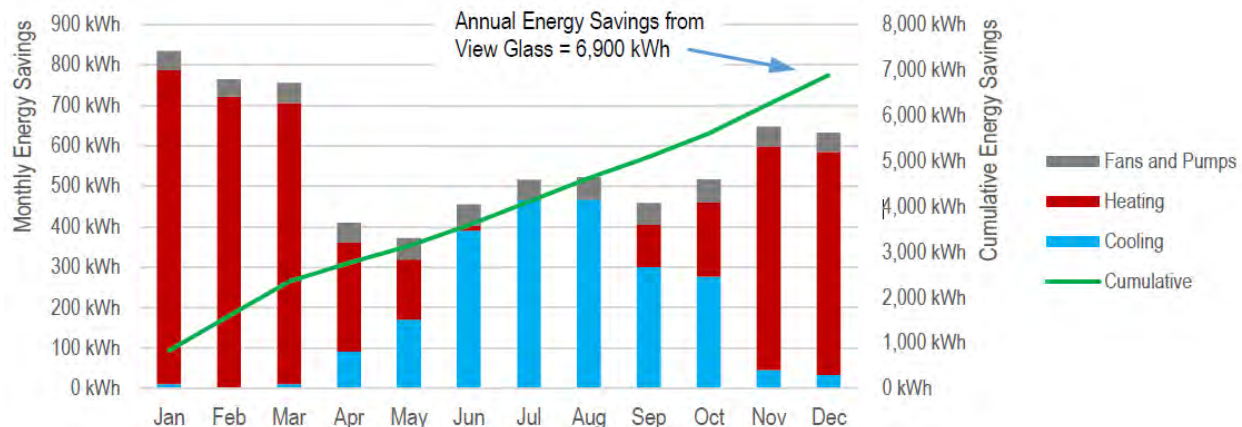


Figure 26. Estimated Energy Savings from View Dynamic Glass by Month

Annual energy savings for the 2nd floor south façade were 6,900 kWh. To put this energy saving into relative terms, those savings are equivalent to about 6.0% of the annual HVAC energy consumed by the retrofitted spaces. From an Energy Usage Intensity (EUI) perspective, the Dynamic In-Fill saved these spaces about 5.6 kBtu/sf/year as shown in Figure 27. The extremely high heating energy is caused by the inefficient electric resistance reheat. Being in the denominator of the percent calculation, this high heating energy base is the main cause of the seemingly low relative savings of 6.0%.

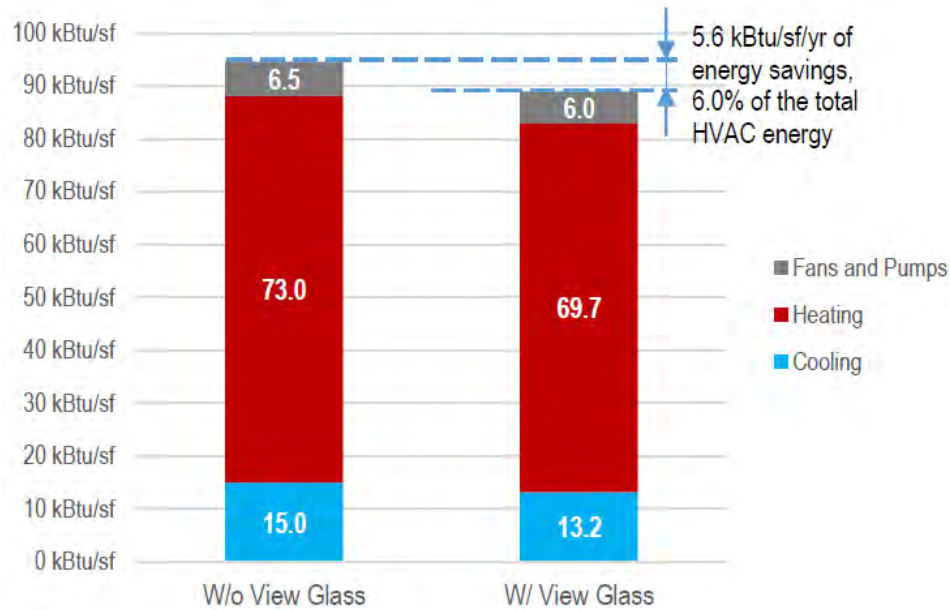


Figure 27. HVAC EUI Savings from Dynamic In-Fill glass

The modeled View Dynamic Glass tinting schedules are displayed in below as a verification of the proper tinting control in the energy model. The graphs below illustrate that the model considered the glass tinted for much of the day (12+ hours) for up to 60 minutes per hour. In practice, the occupants may choose to tint the glass more or less than these modeled activity plots, but they demonstrate that the model results reflect the active use of the glass.

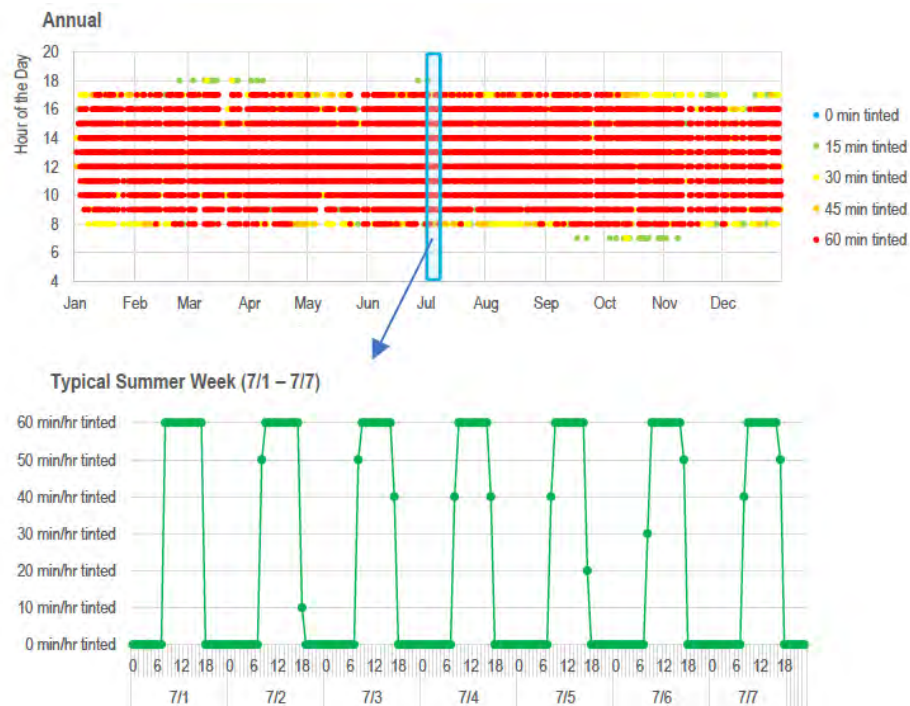


Figure 28. Dynamic In-Fill Tint Schedule for the Calibrated Energy Model

6.2 PEAK LOAD IMPACT:

The Dynamic In-Fill glass system is intended to tint during peak cooling load periods, thereby blocking unwanted solar radiation and yielding savings in peak load cooling energy use. This also results in reduced HVAC equipment sizing as well as system simplicity when compared to traditional glazing solutions.

Figure 29, below, compares the peak cooling load of a typical office where Dynamic In-Fill was installed as compared to its estimated to be its peak cooling load prior to the window retrofit. By switching from the baseline glass to View Dynamic Glass, the total peak cooling load and the solar heat addition at the cooling peak period were reduced by 23% and 67% respectively. It can also be noted that the peak cooling time was shifted from 1 PM, when the thermal mass in the wall had not been saturated by the high outdoor temperature and solar radiation (surface conduction heat addition is very low), to 5 PM after the full benefit of thermal mass had been harvested. This shift indicates a co-benefit between high thermal mass constructions and View Dynamic Glass in the effort of peak cooling load reduction.

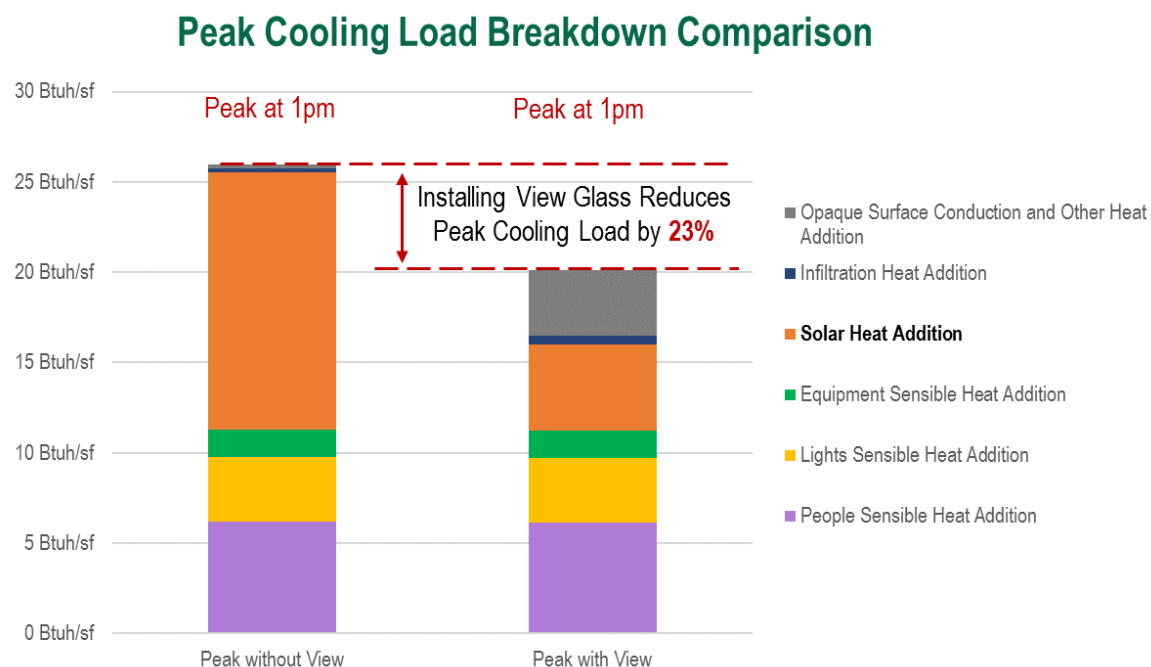


Figure 29. Peak Cooling Load Breakdown Comparison

The implications of the peak cooling benefits are multiple. First, the size and complexity of required HVAC system is reduced by approximately 23%. While the current demonstration installation did not need or plan for an HVAC refresh or retrofit, that replacement system could be downsized for considerable financial savings when it does occur. View previous demonstration project, at MCAS Miramar, saw similar downsizing opportunities for a building planning for an HVAC refresh in the near future. When that scheduled upgrade took place, the replacement HVAC was 20+% smaller and less expensive.

Second, the time shift of the peak-cooling requirement is also important in its implications to energy cost and consumption. By shifting the load to off-peak hours, buildings can shave time-of-use costs associated with peak usage times. Further, because the peak cooling requirement coincides with the end of the work day, the facility may avoid the cost (and associated GHG emissions) of cooling for a fully occupied facility.

As found by the analysis, the time shifted peak occurred at 5 PM for the Dynamic In-Fill offices. This was due to the thermal saturation of the historic brick façade and not associated with the heat rejection limits of the dynamic glass. Better heat rejecting opaque envelope (e.g. high albedo stucco) could shift that peak later into the evening or further reduce its severity.

6.3 ADDITIONAL RESULTS

Additional findings of the project demonstration project energy analysis include the following highlights:

- Installing View Glass reduces HVAC energy throughout the year.
- Relative annual HVAC energy savings is 6.0%.
- The overall EUI savings is 5.6 kBtu/sf.
- High heating energy is due to the very inefficient electric resistance reheat.
- The Dynamic In-Fill reduced the asymmetric heating/cooling along the building. The conditioning system was better balanced for higher comfort
- Additional energy savings may be harvested if the system is coupled with good daylighting design.

6.4 OCCUPANT COMFORT:

In addition to the demonstration's primary objective of assessing energy savings, the project and site also offered an opportunity to compare the comfort of similar spaces with and without the Dynamic In-Fill glazing. The definition of comfort defined by ASHRAE Standard 55 was used²⁰, with site measurements of air temperature, humidity, and radiant surface temperatures taken. Surface temperatures were determined through use of infrared photography (using a FLIR D60 camera). The ASHRAE 55 comfort analysis found similar results between spaces with and without View Glass.

For the pair of rooms that had similar direct solar exposure (233 and 133), the View Glass had a 10F lower interior glass surface temperature than the traditional glass pane, (85F vs 95F). As expected, both rooms had the same frame temperature of approximately 100F.

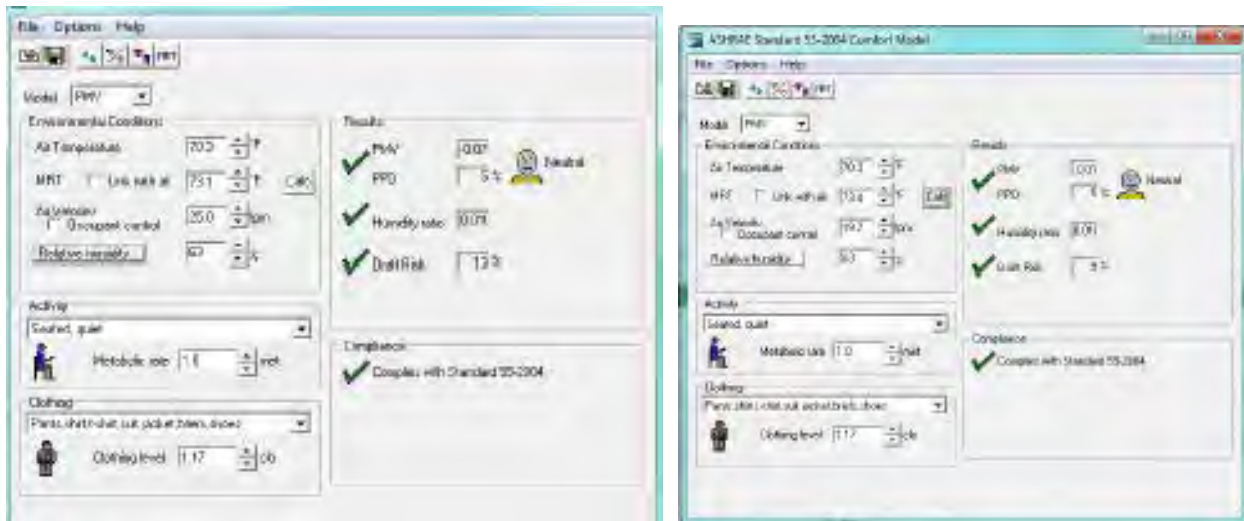


Figure 30. ASHRAE Comfort Model Results for Rooms 233 and 133

While the lower window temperature does impact occupant comfort, at the seating location 6' from the window the air temperature and floor/ceiling/wall temperatures dominated and resulted in the Predicted Percent Dissatisfied being calculated as the same at 5%. The air temperatures in these two rooms were also the same, which suggests similar radiant temperatures since the same air temperature setpoints were in use.

It was observed that the blind position was different, with the louver blinds fully dropped in the traditional glazing room but half open in the View Glass space. This is as expected with the electrochromic glazing offering glare control without blind use.

A second pair of rooms was measured, Rooms 220 and 120. The results from these rooms showed a marked impact from differing solar exposure between the two rooms. The second floor room with View Glass, Room 220, had direct solar incident on the window (resulting in a significant solar load) while the first floor room did not. As a result, the View Glass interior surface temperature was 9.5F higher than the standard glazing, which was not exposed to direct solar. It is understand that for the same solar exposure conditions without View glass, the differences would be much greater and the exposed office would be more uncomfortable. The frame temperatures showed a much higher 28F temperature difference, with the frame in direct solar measured at 109F – appreciably hot to the touch.

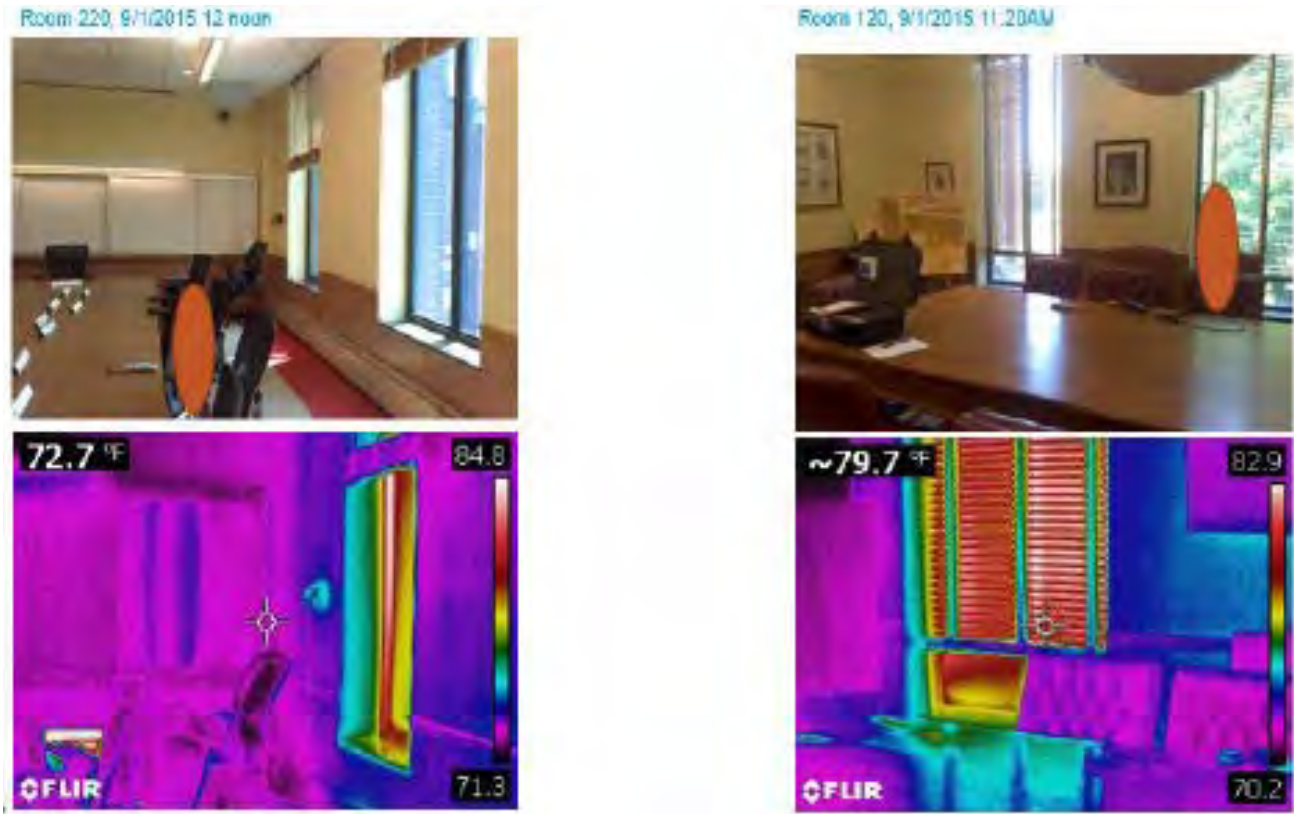


Figure 31. Photographic and Thermal Imaging for Rooms 220 and 120

The difference in observed window and frame surface temperature differences were large enough to result in a just measureable difference in the comfort metric between the two spaces, with the Dynamic In-Fill space resulting in a 7% Predicted Percent Dissatisfied versus 6% for the standard glazing space (which was not in direct solar) exposure. The room in direct solar was also observed to have a similar air temperature, 71.4F versus 72.2F, which helped compensate for the higher radiant temperatures at the exterior. The difference in solar exposure between the first and second floor rooms would be expected to impact occupant comfort. Although the difference between conditions prevents a direct comparison between perceived comfort, these results may be interpreted to indicate that a sun exposed office with Dynamic In-Fill has similar comfort ratings and temperatures as that of a standard window unexposed to direct sun. This is the objective of the dynamic product, to manage the solar heat and create an ambient light environment.

Table 4. Summary of Performance Objectives Versus Measured Results

Performance Objective	Metric	Success Criteria	Results
Quantitative Performance Objectives			
Annual HVAC/Lighting Energy Usage	Energy Intensity (kWh/ft ²)	>15% annual energy savings over existing glass	6% annual energy reduction
Building Peak Load	Peak Power Intensity (kWh/ft ²)	>25% peak energy reduction over existing glass	23% peak load reduction
Lifecycle GHG emissions	Metric tons CO ₂ via complete LCA	>24% savings over existing	8% GHG reduction
Life Cycle cost	Dollars spent	50% lower installed cost versus dynamic glass replacement	2x savings over dynamic glass replacement
Qualitative Performance Objectives			
Occupant Comfort	Likert-type survey results plus real time data	Statistically significant gains in comfort	Lower glass temps and gain. Similar comfort due to occupant displacement from glass.
User Awareness and Acceptance	Survey results and reactions	Statistically significant gains in satisfaction	High adoption and satisfaction with site facilities management and occupants

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7.0 COST ASSESSMENT

7.1 ASSUMPTIONS FOR COST PROJECTIONS

In addition to developing models to predict the energy and greenhouse gas benefits of dynamic glass technology, the project team also developed an empirically derived economic model to assess the deployment costs and benefits for the installation site and for other similar DOD buildings. For this, several assumptions about expected project costs were made. These included:

Glass (IGU) Costs: The total cost from the glass vendor. For the low-e baseline, this includes glass material cost only. For the dynamic scenario, the glass cost includes the dynamic IGU, associated electrical components, and commissioning.

Shading Costs: Glare control blinds are assumed to be an installation requirement on low-e replacement windows, but not dynamic windows. Cost for the installed blackout shades was researched and assumed to be \$15/sqft. The additional wooden, horizontal louvers were assumed to be \$40/sqft. The assumed average usable lifetime of blinds is 10 years, with maintenance cost of \$0.15/sqft/yr. The use of both blackout shades and premium wooden louvers is atypical of mainstream commercial offices and existing government facilities. In typical spaces, existing blinds are likely narrow, metal horizontal blinds or non-metal vertical blinds. These can have lower replacement costs; on the order of \$10 – 15/sqft installed. For offices with roller shades, costs are slightly higher, approximately \$20/ sqft for manual shades and up to \$40/sqft for motorized shades.

HVAC Costs:

For the present installation, cost calculations were based on the existing DOAS plus fan coil units system. Estimated service life for the system is 20 years and the cost for end of life replacement is approximately \$2,100/ ton.

For the building stock HVAC costs, a more general approach was adopted. Depending on the type of HVAC system, the installed cost, system life, and maintenance cycle can vary widely. Because of the wide variety of solutions in place in the current DoD building stock, the project team needed to simplify the approach and to select a reasonable set of costs and equipment lifetimes. For this, the project team drew on an internal library of 100+ reviewed energy models and the informed input from a multiple principals at a leading MEP firm (Integral Group <http://www.integralgroup.com/>). It was determined that the assumed average usable lifetime of a typical HVAC system is 15 years. (This estimate is deemed conservative. HVAC maintenance costs were assumed to be 1% of system cost. It is worth noting that the model assumed the estimated service life of the equipment versus the actual or observed service life of the HVAC equipment. Tabulating benefits beyond the recommended best practices is inappropriate and represents a reasonable, if conservative estimate. Using anticipated equipment lifetimes is also consistent with how the service life of the glazing system was estimated (30 years vs. 50+ years typical actual service of glass).

It was also assumed that any future HVAC upgrades will be downsized to the revised and proper peak-load requirement for the building for a given window condition (for either dynamic or low-e windows).

In calculating the total costs for the demonstration project, it was assumed that an HVAC replacement was eminent due to the end the existing unit's serviceable life. This assumption was verified as accurate by the base facilities team.

Building lifetime: It was assumed that each site has a remaining service life of 30+ years and the full benefits of glazing and HVAC upgrades will be realized for one refresh cycle.

Energy: Energy results were derived directly from the validated Energy Plus whole building model. Total savings due to efficiency gains were calculated by multiplying energy savings (kWh) by actual Washington DC utility rates (\$/kWh)²¹. For broader energy cost projections, the project team used regional energy costs obtained from the EIA. For Q2 2017, the US national average cost of commercial electricity is \$0.104 per kWh. Regional prices range from the lows in the West South Central (\$0.0844 / kWh) and South Atlantic (\$0.0942 / kWh); to moderate costs East North Central (\$0.1016 / kWh) and East South Central (\$0.1050 / kWh); to the upper range in regions of New England (\$0.1496 / kWh) and Pacific Contiguous (\$0.1233 / kWh). (Note: Alaska and Hawaii are exceptionally higher rates at \$0.2357 / kWh average.)²²

It was assumed that energy costs will increase 2% annually. This is consistent with national recognized energy prediction models.

Electrical Labor costs: Electrical labor cost for wiring dynamic glass BOS components throughout the façade and bringing power to the control box was calculated using the RS Means construction labor reference guide and actual quotes/bids from mechanical contractors and engineering firms for other dynamic glass installations.

7.2 COST ANALYSIS

All cost assessments were done using simple payback and savings-to-investment ratio over a 30-year period using the NIST BLCCA process (NIST Handbook 135²³). Using our measured data and energy models, we projected the future potential energy and cost savings (including future capital and maintenance costs from HVAC and blinds replacements) from the use of dynamic windows as compared to traditional low-e glazing at each site.

The model includes an analysis based on a simple ROI/payback and the total realized benefits over a 30-year lifecycle. Each analysis was broken into two categories of expenditures: Capital expenditures (CAPEX), which captures all first time costs/savings including the HVAC system and peripheral components retrofit cost, and window shades/blinds costs.

Also broken out is the second category of Operating expenditures (Opex), which is a total of all reoccurring expenses/savings impacted by the efficiency measure on an annual basis. Opex captures the costs associated with energy consumption, HVAC maintenance, and window shades/ blinds maintenance. A description of each line item and section are listed in the tables below, along with any stated assumptions. All assumptions on glazing, materials, equipment, labor, utility rates, etc. were gathered by industry standard reference sources such as the RS Means Construction Cost guide and actual quotes/bids from mechanical contractors and engineering firms. These are summarized in Section 7.1, above.

7.3 COST ANALYSIS AND COMPARISON

As seen in Section 6, Dynamic In-Fill glass has a measurable impact on annual energy and peak load reduction. This results in: 1) energy costs and demand charge savings, 2) capital equipment cost savings (e.g. HVAC downsizing and elimination of blinds/shades), and 3) maintenance cost savings (e.g. from HVAC and blinds). The economic impact of retrofitting with View dynamic glass was compared against retrofitting with low-e glass, both with dimmable lights. Table 5 shows the “first costs” of integrating dynamic windows as part of a modest energy efficiency or modernization retrofit.

For this example, based on market data for typical horizontal metal blinds, installed shading costs are assumed to be \$15/sqft with a typical replacement cycle 10 years. This is not representative of the War College installation, which had a premium, dual blind solution installed at the time of the demonstration project.

Table 5. Capital First Costs (and Lifetime Costs), Plus Annual (and Lifetime) Operational Savings, Including Lifetime Total Cost of Ownership.

All costs normalized to sqft glass.

Capital First Costs (30 year Lifetime Capital Costs) for Retrofits		
Component	Low- E Glass System	Dynamic Glass System
IGU (\$/sqft glazing)	\$20 (\$20)	\$40 (\$40)
Window Frame (\$/sqft glazing)	\$30 (\$30)	\$10 (\$10)
Installation Labor (\$/sqft glazing)	\$25 (\$25)	\$10 (\$10)
Low Voltage Labor (\$/sqft glazing)	\$0 (\$0)	\$2 (\$2)
HVAC Capex Cost (\$/floor sqft)	\$21 (\$32)	\$17 (\$26)
Shading Capex Cost (\$/sqft)	\$15 (\$45)	\$0 (\$0)
Total Net Capital First (Lifetime) Costs (\$/sqft glazing)	\$112 (\$152)	\$79 (\$88)
%-Increase	NA	-30% (-42%)

Annual (Lifetime) Operational Expenses		
Element	Low-E Glass System	Dynamic Glass System
Energy Consumption (\$/floor sqft /yr)	\$1.64	\$1.54
HVAC Maintenance (\$/ floor sqft/yr)	\$0.13	\$0.11
Shading Maint. (\$/glazing sqft/yr)	\$0.15	\$0
Total Annual (Lifetime) Cost (\$/sqft)	\$1.92 (\$58)	\$1.64 (\$49)
%-savings		15% savings
Lifetime Total Cost of Ownership (\$/glazing sqft)	\$215	\$141

Table 6 shows the overall economic analysis for this site for the first year. As can be seen in the table, there are multiple potential savings from the use of dynamic glass. In terms of capital and operational savings, the use of dynamic glass saves \$82,000 in HVAC equipment up-front, plus an additional \$82,000 for future HVAC replacements during the lifetime of the windows (assumed to occur every 20 years) and \$30,000 savings on HVAC maintenance during this same period. Dynamic glass also results in \$27,000 in up-front savings for shading attachments, plus an additional \$54,000 savings on future shading replacement during the lifetime of the windows (assumed to occur every 10 years) and \$9,000 savings on shades maintenance during this same period. Finally, the use of dynamic glass saves approximately \$1,100 in electricity per year, or \$33,000 in electricity savings over the lifetime of the windows. Overall, dynamic windows results in a \$222,000 lifetime return on investment.

Table 6. Year 1 CapEx and OpEx comparison between upgrading with View Dynamic Windows vs State of the art Low-e windows.

Low-E vs View Dynamic Glass			
Façade Package	Low-e	Dynamic	
Glass	1,500 sf	1,500 sf	
Internal Shading	Manual blinds + horizontal louvers	None	
Exterior Shading	None	None	
Dimmable lights	Yes	Yes	
First Time Costs (CAPEX)	Low-e (\$)	Dynamic(\$)	Difference (Savings)
Glass installed cost	112.5	90K	(70.5K)
Electrical labor	-	3K	4K
HVAC	176K	143K	(33K)
Internal shades	22.5K	-	(22.5K)
External shading			
Total CAPEX	\$311K	\$236K	(\$72K)
Annual Operating Costs (OPEX)	(\$)	(\$)	Difference (Savings)
Energy consumption	18K	16.9K	(1.1K)
HVAC maintenance	1.4K	1.2K	(0.2K)
Shading maintenance	0.3K	-	(0.3K)
Total OPEX	\$19.7K	\$18.1K	(\$1.6K)
*Assumptions			
Low-e Glass cost	\$20/sf glass cost; \$75/sf installed cost		
View Dynamic Glass cost	\$40/sf glass cost; \$60/sf installed cost		
Electrical labor (dynamic only)	\$2.00/sf		
HVAC savings	7.0 ton reduction @ \$1,600/sf		
HVAC CFM reduction	4,669 CFM; \$4.08/CFM		
HVAC related components	23% reduction from baseline of \$12/sf of		
Energy consumption savings	6% from baseline energy consumption		
HVAC Maintenance	1.0%/year of HVAC cost		
Internal shades	\$15.00/glazing sf		
External shades	None		
Shading maintenance	\$0.15/glazing sqft/yr		

Table 7 depicts the output of a standard NIST BLCCA analysis for this site. Year 1 Savings-to-Investment (SIR) ratio is 0.83, with a payback of less than 3 years. The 30-year SIR is 2.46, with a total lifetime cost savings of \$222,000. This case study recognizes that View windows and state-of-the-art Low-e windows both have an expected lifetime of 30 years, as does building The National War College facility.

Table 7. NIST BLCCA Cost Analysis and 30-year Savings to Investment Analysis

Dynamic vs Low-E	Years				
	1	5	10	20	30
Initial Investment (Windows) (\$k)	90	90	90	90	90
Other Capex Savings (\$k)	72	72	72	144	144
Energy Savings (\$k)	1.1	5.5	11	22	33
Maintenance Savings (\$k)	1.5	7.5	15	30	45
Total Savings (\$k)	74.6	85	98	196	222
Savings/Investment	0.83	0.94	1.08	2.18	2.46
Payback	6 Years				

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8.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED

At the center of this technology's successful demonstration is its full compatibility with modern construction practices and delivery channels. The innovation of an active coating is delivered in a novel, cost-effective form factor that is acceptable to construction trades, facilities operators and historical societies. Further, the energy saving and comfort benefits apply to a broad spectrum of DOD building types and locations. However, these intrinsic technology advantages can create multiple project hurdles.

8.1 PROCUREMENT AND INSTALLATION

With regards to the demonstration project, there were no procurement or installation issues. View dynamic glass is positioned as a smart glass product designed for purchase and installation by DOD-qualified glazing subcontractors and low voltage subcontractors, as was the case with this project.

For future installations, it should be noted that the subcontractors control the product markup and installation pricing. As a result, it can vary based on the region of the country and the familiarity of the contractor with our product. This potential issue can be mitigated through active training and education of installers.

Further, because View dynamic glass is procured by the glazier and not the government directly, it is not currently listed on the GSA Purchasing Schedule. This has not been a barrier to date, but that situation may change. If so, View dynamic glass will become listed on the Purchasing Schedule in the future.

8.2 STRUCTURAL LOAD

There were no structural load issues with the demonstration project. View dynamic glass weighs approximately the same as traditional low-e insulated glass units (approximately 4 pounds per square foot). However, for future renovation and retrofit projects where single pane glass is being added to, the additional skin load can potentially be an issue (as would complete renovation with any dual-pane low-e or dynamic windows). As such, in renovation projects where single pane glass is in place the project team should include a structural engineer in early discussions.

8.3 WINDOW OPERABILITY

For this demonstration project, no operable windows were present. For historic buildings, operable windows are commonplace and could be incompatible with the present solution. operable windows had been in place for decades, with employees accustomed to their presence and flexibility.

If operable windows are present, the change of window operator type should be considered as a potential objection in future installations. Although there are positive energy benefits, occupants tend to reject the loss of operability and can weigh that against the energy and comfort benefits of dynamic glass. When possible, replacement dynamic glass windows should match the prior operation type. Note that View dynamic windows are available in operable, as well as inoperable formats.

8.4 OCCUPANT TRAINING

With the experience from this project, we learned that occupant training is a key element of project commissioning and should be included as a project milestone in any installation. Following the successful completion of this project, the project team feels that it may be the most important milestone for successful adoption.

The basis of the training should be to set expectations on glass tint transition time. The glass is designed to predictively tint and clear to maximize comfort. This is a gradual process that may occur infrequently throughout the day. However, occupants expected the glass to transition quickly and often in response to non-comfort or energy conditions. If occupants' expectations are not aligned with the glass' purpose and performance, it may be rejected as a technology due to a misunderstanding.

It is recommended that future project teams share key features and benefits of dynamic glass with the building occupants both before and after the product installation. Occupants should also be encouraged to participate in satisfaction surveys designed to improve the behavior algorithm for that project site.

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APPENDIX A ENERGY MODEL AND ANALYSIS

View Dynamic Glass Energy Analysis Report

Executive Summary

View Dynamic Glass Energy Analysis Report

To: View Dynamic Glass – Deepika Khowal
 By: Integral Group – Liyang Han, Bungane Mehlomakulu
 Date: 1/20/2016

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1 Introduction

1.1 Background

1.1.1 Technology Overview – View Glass

Smart Windows are a category of next generation windows that have the ability to change traditionally static performance characteristics such as visible light transmittance and solar heat gain coefficient. Examples of technologies that enable Smart Windows are electrochromic (EC), thermochromic, photochromic, liquid crystal (LC) and suspended particle devices (SPD). Thermochromic and photochromic technologies change their properties based on ambient temperature and light respectively. EC, LC and SPD technologies have the advantage of electronic control of glass performance, enabling truly intelligent controls that can be integrated with occupant schedules, lighting levels, or algorithms to increase building energy efficiency. Unfortunately, both LC and SPD require continuous high voltage AC to operate and their failure mode is dark. EC technology has the advantage of using low voltage, low energy consumption and a failure mode being clear. In addition EC is the only technology that has passed the rigorous ASTM standard for accelerated environmental durability which is equivalent to >50yr lifetime. The application of EC technology to windows can substantially reduce the energy consumption of buildings by reducing cooling and heating loads as well as the demand for electric lighting.

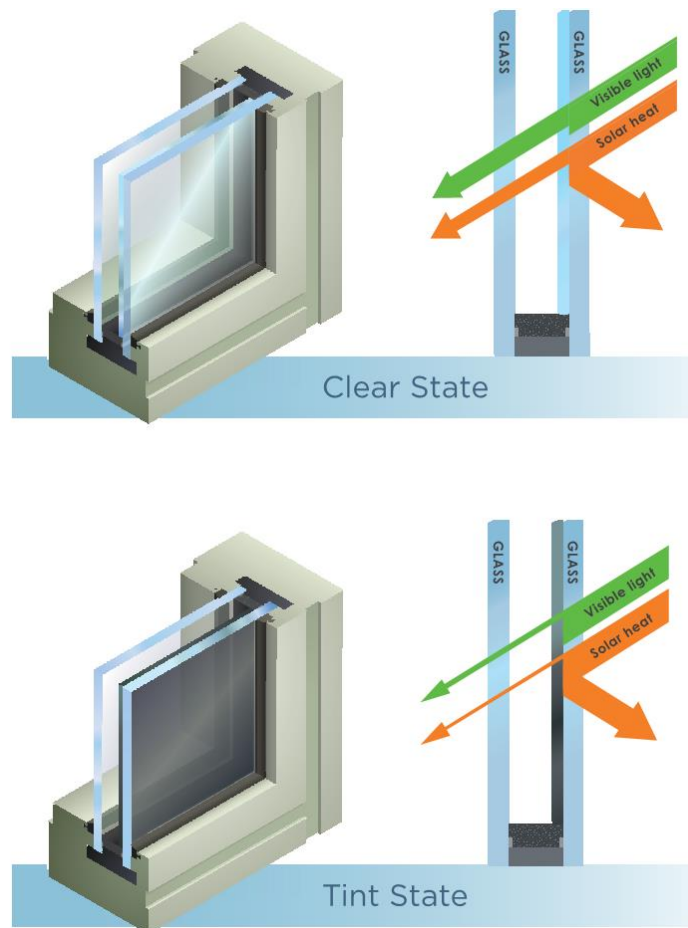


Fig. 1-1 View Dynamic Glass Solar Transmission Properties – Clear State vs. Tint State

View Dynamic Glass uses EC technology to change solar transmittance properties (in the ultra-violet, visible and infrared spectrum) in response to a small applied voltage (< 5 volts). This enables control of the amount of light and radiative heat passing through a window that results in a window that ranging from a tinted transparent state to a clear transparent state (**Fig. 1-1**). In addition, the coating has low emissivity properties, adding to the thermal performance when combined into a dual pane insulating glass unit (IGU). View Dynamic Glass is beneficial to all types of buildings as a method of controlling solar heat gain and light levels.

1.1.2 Site Background – the National War College

The National War College (**Fig. 1-2**) of the United States is a school in the National Defense University. It is located in Theodore Roosevelt Hall on Fort Lesley J. McNair, the oldest active Army Post in existence today. The building was constructed in 1903 with high-mass brick construction.



Fig. 1-2 National War College

View Dynamic Glass on the South façade of the building's second floor to replace the existing single-pane clear glass. **Fig. 1-3** shows the floor plan of the second floor of Theodore Roosevelt Hall marked with the View Dynamic Glass installed locations.

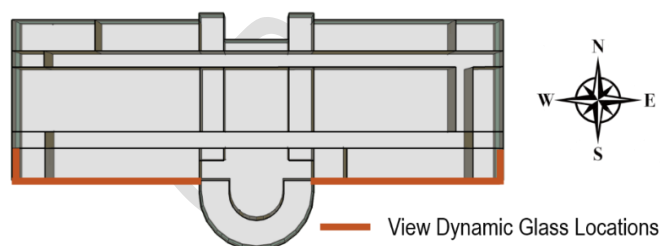


Fig. 1-3 View Dynamic Glass Installed Locations

1.2 Goal and Methodology

The goal of this study is to quantify and document the energy savings incurred by replacing the existing single-pane glass with high-performance View Dynamic Glass. Due to the lack of measured historical energy consumption data, an energy calibration approach was adopted by following the steps below:

1. Submeters were installed on the entire second floor of the building to monitor electrical receptacle, lighting and HVAC energy at the panel level for a period of about two week when the floor experienced school-in-session occupancy.
2. A calibrated energy model for the second floor was developed to match the two-week metered conditions (post-installation period of View Dynamic Glass) in OpenStudio¹. Additional information includes drawings provided by the college, and window control and modeling strategies provided by View. The baseline model (pre-installation period of View Dynamic Glass) was then obtained by modifying the window properties of the calibrated model to match existing windows.
3. A comparative analysis was conducted by comparing the energy consumption of the baseline model and the calibrated model for spaces that experienced the window retrofit to determine the energy savings from View Dynamic Glass.

¹ OpenStudio is a building energy modeling front-end software widely adopted in building engineering. Its primary simulation engine is EnergyPlus, an open-source energy simulation program funded by the U.S. Department of Energy (DOE) and developed in collaboration with the National Renewable Energy Laboratory (NREL), various DOE National Laboratories, academic institutions, and private firms.

2 Energy Model Calibration

2.1 Calibration Process

In order to estimate the energy savings from installing View Dynamic Glass, an energy model representing the building operation after the window retrofit was developed and calibrated to measured data over a period of about two weeks. Constrained by the existing panel layout and HVAC thermal zone definition, it was very difficult to measure the energy usage only in spaces where the window retrofit took place. Taking into account the flexibility of parsing out the energy usage for the retrofitted spaces in the energy model, the scope for the on-site submetering as well as the calibrated model was expanded to the entire second floor. In developing the calibrated energy model for the case with View Dynamic Glass, the following steps were taken.

1. Metered data was collected for the period of September 2nd, 2015 to September 16th, 2015.
2. An energy model (later referred to as the calibrated model) was built for the second floor of the National War College to match the construction and mechanical design as shown on the drawings provided by the college.
3. View Dynamic Glass was modeled in the calibrated model with an overall U-value (including framing effect) of 0.35 Btu/sf/hr/°F and two tint states, with its clear state having a Solar Heat Gain Coefficient (SHGC) of 0.28 and tint state 0.18. Under View's guidance, the glass was modeled to tint when the solar incidence level on the glass exceeded 25 Btu/sf/hr. Please refer to Appendix B.2.1 for detailed View Dynamic Glass properties.
4. The energy model's lighting and receptacle energy were calibrated to match the metered data, marking the completion of energy model calibration.

2.2 Energy Model Detailed Description

A 1-story building was modeled to represent the 2nd floor of the National War College building (floor plan shown in **Fig. 2-1**). Its floor construction was defined as adiabatic to prevent heat transfer with the ground because in reality, the 2nd floor is not in direct contact with the ground and the vertical heat transfer between floors is minimal assuming all spaces are conditioned to similar setpoints.

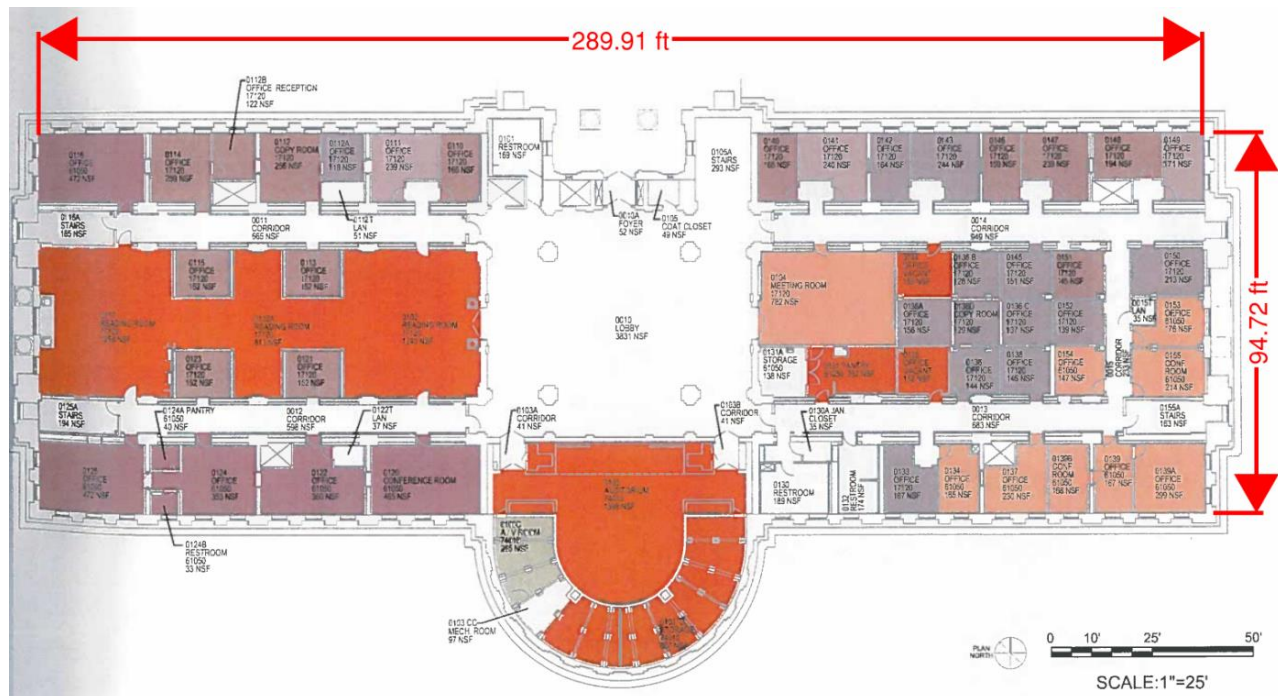


Fig. 2-1 National War College 2nd Floor Plan

Screenshots of the geometry of the energy model are shown in **Fig. 2-2**. The window-to-wall ratio was estimated to be 40% (refer to Appendix B.1.2 for detailed building inputs). The primary HVAC system type is fan coil units with dedicated outside air systems. A rooftop chiller and an electric resistant water heater supply chilled water and hot water respectively to the fan coil units.

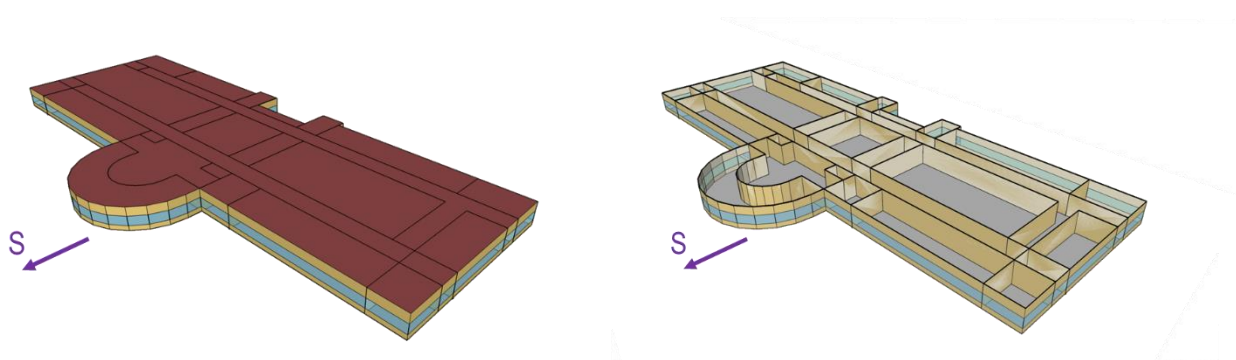


Fig. 2-2 Energy Model Geometry (Left: Whole Building, Right: Whole Building with Roof Hidden)

2.3 Model Calibration Results

As shown in **Fig. 2-3**, the modeled receptacle energy matches up to the measured data within a reasonable error range (<4%). Due to the limitation of the existing panel layout (Appendix A – Calibration Panel Layout) in the building, the measured lighting energy and HVAC energy were combined in the collected data, which made it difficult to calibrate the lighting and HVAC energy separately. With reasonable assumptions of the mechanical equipment efficiencies and schedules (Appendix B.1.2), the lighting power density was then adjusted to achieve similar combined energy consumption of HVAC and lighting as the measured data (<5% discrepancy).

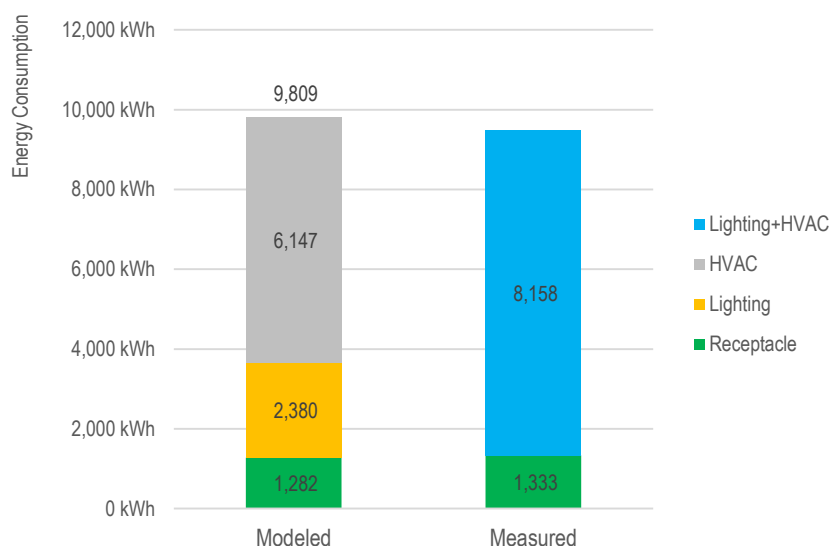


Fig. 2-3 Energy Consumption for the Calibration Period of 9/2/2015 – 9/16/2015 (Modeled vs. Measured)

The calibrated lighting and receptacle inputs are listed in **Fig. 2-4**. Although the calibration was conducted for the whole 2nd floor model, shown below are only inputs for spaces that experienced the window retrofit because only these spaces are analyzed in the following energy performance assessment. For a complete list of calibrated model space inputs, please refer to Appendix B.1.3.

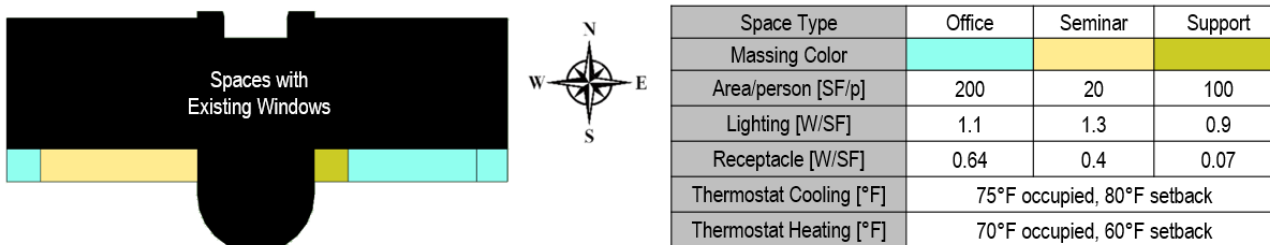


Fig. 2-4 Calibrated Inputs for Spaces with View Dynamic Glass

3 Performance Assessment

3.1 Annual Energy Savings

A baseline model was created by modifying the calibrated model. The only change made in this process was to replace the View Dynamic Glass with a window construction that has an overall U-value of 0.53 and SHGC of 0.53. Both the baseline model and the calibrated model were then simulated for the whole year using the TMY3 weather data for Washington, DC. The energy consumption data for spaces that experienced the window retrofit was extracted from both models and compared against each other to quantify the savings from installing View Dynamic Glass. **Fig. 3-1** shows the estimated monthly and annual energy savings from the recent installation of View Dynamic Glass in the National War College.

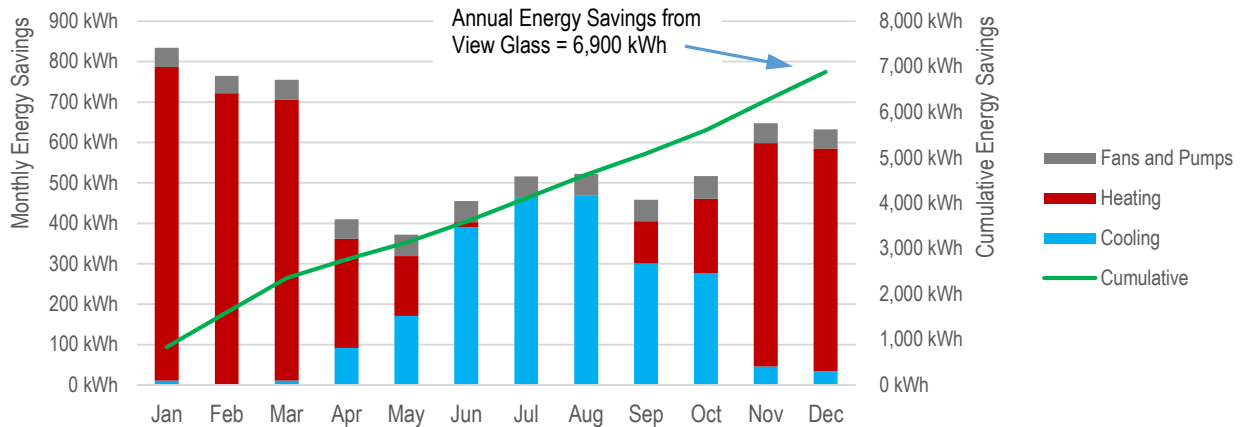


Fig. 3-1 Estimated Energy Savings from View Dynamic Glass by Month

To put this energy saving into relative terms, it is equivalent to about 6.0% of the annual HVAC energy consumed by the retrofitted spaces. From an Energy Usage Intensity (EUI) perspective, View Dynamic Glass saves these spaces about 5.6 kBtu/sf/yr as shown in **Fig. 3-2**. The extremely high heating energy is caused by the inefficient electric resistance reheat. Being in the denominator of the percent calculation, this high heating energy base is the main cause of the seemingly low relative savings of 6.0%.

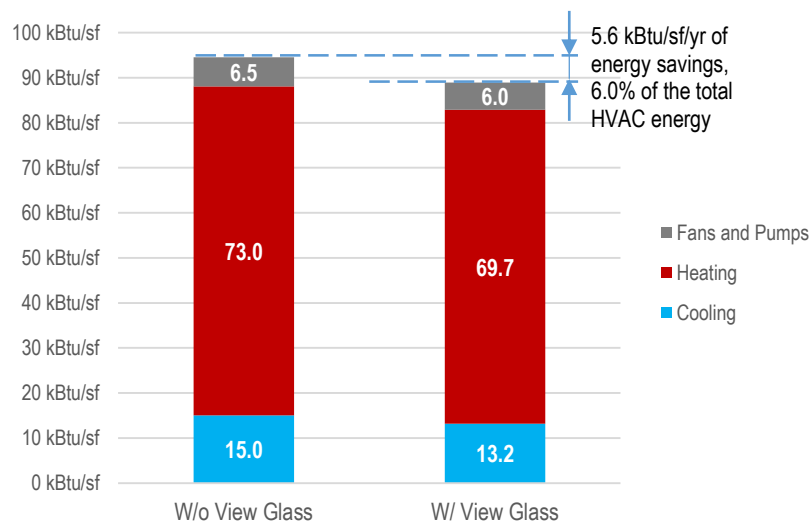


Fig. 3-2 HVAC EUI Savings from View Dynamic Glass

The modeled View Dynamic Glass tinting schedules are displayed in Appendix B.2.2 as a verification of the proper tinting control in the energy model.

3.2 Peak Demand Reduction

View Dynamic Glass can tint during peak cooling load periods, thereby blocking unwanted solar radiation and yielding savings in peak load cooling energy use. This also results in reduced HVAC equipment sizing as well as system simplicity when compared to traditional glazing solutions.

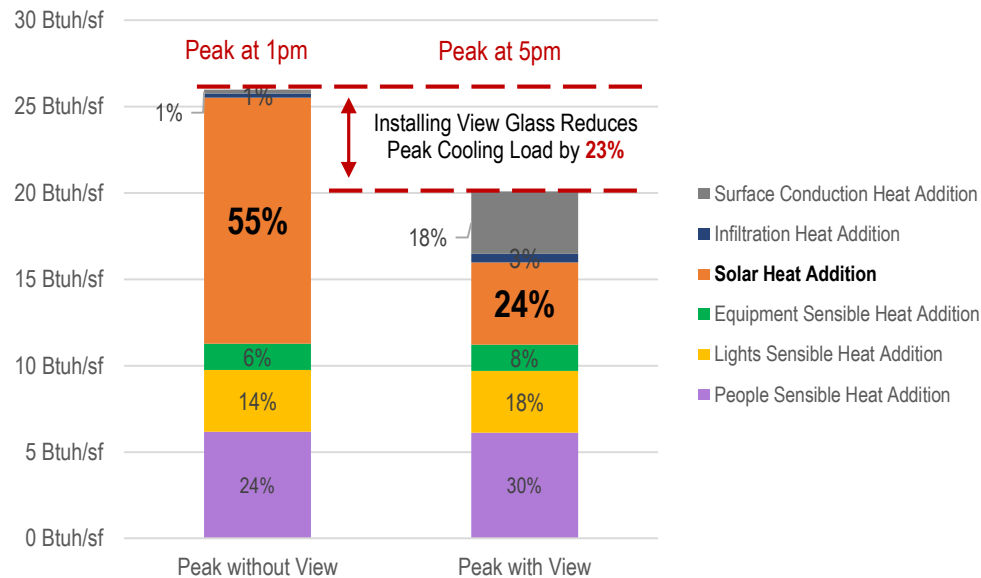


Fig. 3-3 Peak Cooling Load Breakdown Comparison

Fig. 3-3 compares the peak cooling load of one of the offices where View Dynamic Glass was installed to what is estimated to be its peak cooling load prior to the window retrofit. By switching from the baseline glass to View Dynamic Glass, the total peak cooling load and the solar heat addition at the cooling peak period were reduced by 23% and 67% respectively. It can also be noted that the peak cooling time was shifted from 1pm, when the thermal mass in the wall had not been saturated by the high outdoor temperature and solar radiation (surface conduction heat addition is very low), to 5pm after the full benefit of thermal mass had been harvested. It indicates a co-benefit between high thermal mass constructions and View Dynamic Glass in the effort of peak cooling load reduction.

4 Appendix

Appendix A – Calibration Panel Layout

Electricity consumption data was measured using eight existing panels on the second floor of the National War College building as listed in **Table 4-1**.

Table 4-1 National War College 2nd Floor Panel List

#	Panel	Location	Type	Load Type
1	RIN-2A2	NW	Hobo	Lighting or HVAC
2	RIN-2A1	SW	Hobo	Lighting or HVAC
3	CIN-2A1	SW	Dent	Plug Load
4	RIN-2B1	SE	Dent	Lighting or HVAC
5	RIN-2B1	SE	Hobo	Lighting or HVAC
6	CIN-2B1	SE	Hobo	Plug Load
7	R1N-2B2	NE	Dent	Lighting or HVAC
8	C1N-2B2	NE	Hobo	Plug Load

The corresponding panel locations are displayed in **Fig. 4-1**.

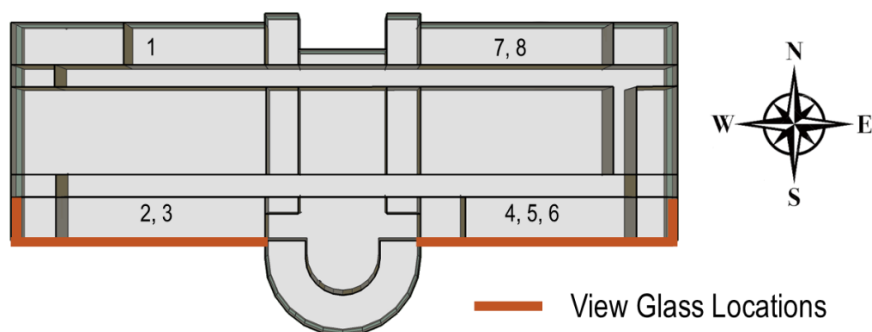


Fig. 4-1 Calibration Panel Locations

Raw data was measured at 1-min increment. **Table 4-2** shows the daily total consumption at each panel.

Table 4-2 Daily Energy Measurement by Panel

Panel	R1N-2A2	R1N-2A1	C1N-2A1	R1N-2B1-dent	R1N-2B1-hobo	C1N-2B1	R1N-2B2	C1N-2B2	Total
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
9/2/2015	19	61	35	46	102	16	325	5	608
9/3/2015	19	62	36	50	104	16	350	6	642
9/4/2015	18	63	37	49	103	15	345	6	636
9/5/2015	11	47	33	44	92	13	221	5	466
9/6/2015	11	47	33	44	92	13	226	5	471
9/7/2015	13	50	33	44	94	13	253	5	506
9/8/2015	18	61	37	51	101	16	332	6	621
9/9/2015	19	64	35	45	101	15	368	6	652
9/10/2015	19	66	35	51	104	16	397	6	693
9/11/2015	18	64	35	49	104	15	399	6	691
9/12/2015	12	47	32	44	92	14	273	5	519
9/13/2015	12	49	32	47	93	14	233	5	484
9/14/2015	19	66	34	51	103	16	386	6	681
9/15/2015	18	62	34	51	109	16	353	6	649
9/16/2015	19	61	33	47	105	16	374	6	660

Appendix B – Energy Model Inputs

B.1 Model Inputs

B.1.1 Project Inputs

Table 4-3 Project Basic Inputs

Project / Building	National War College
Occupancy	Education
Location	Washington, D.C.
Weather File	Arlington-Ronald.Reagan.Washington.Natl.AP
Climate Zone	4

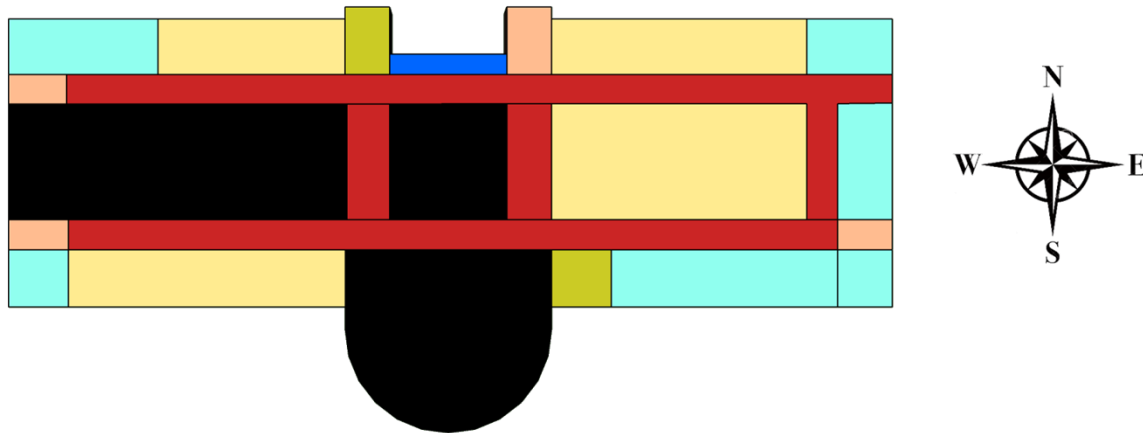
B.1.2 Building Inputs

Table 4-4 Building Architectural, Electrical and Mechanical Inputs

Architectural	
Walls	16 inch Stone Wall w/o insulation
Roof	R-20
Floor	Adiabatic (interior floor)
Infiltration Rate	0.5 ACH
Baseline Glazing U-value	0.53
Baseline Glazing SHGC	0.53
Window-Wall Ratio (WWR)	40%
Electrical	
Interior Lighting Power Density (W/sf)	1.1
Automatic Lighting Controls	No
Daylighting Controls	No
Receptacle Equipment	0.6
Mechanical	
Primary HVAC System Type	DOAS + Fan Coil Units
Cooling Equipment	Cooling Tower + Chiller (COP = 5.5)
Heating Equipment Efficiency	Electric Resistance Heating (EF = 1.0)
Cooling Setpoint	75°F (80°F setback)
Heating Setpoint	70°F (60°F setback)
Thermostat Control	Operative Temperature

B.1.3 Space Inputs

During the energy measurement process, it was noticed that there were panels measuring retrofitted spaces and non-retrofitted one at the same time, making it difficult to only model the retrofitted spaces to compare to the measured data. Therefore, the building energy consumption was calibrated for the entire second floor (described in **Section 2 Energy Model Calibration**) before retrofitted spaces were separated from the model for the final energy savings analysis (**Section 3 Performance Assessment**). Fig. 4-2 shows the space type programming of the second floor and their corresponding space inputs.



Space Type	Massing Color	Area/person [SF]	Lighting [W/SF]	Receptacle [W/SF]	People Sensible [Btu/h-person]	People Latent [Btu/h-person]	Outdoor Air Rate per person [CFM/person]	Outdoor Air Rate per area [CFM/person]	Thermostat Cooling [°F]	Thermostat Heating [°F]
Office	Cyan	200	1.1	0.64	50	200	5	0.06	75°F occupied, 80°F setback	70°F occupied, 60°F setback
Seminar	Yellow	20.0	1.3	0.4	50	200	5	0.06		
Support	Green	100.0	0.9	0.07	50	200	0	0.06		
Corridor	Red	1000.0	0.5	0.16	50	200	0	0.06		
Stair	Orange	N/A	0.6	N/A	N/A	N/A	0	0.06		
Storage	Blue	N/A	0.8	N/A	N/A	N/A	0	0.12	N/A	N/A
Open to Below	Black	N/A	N/A	N/A	N/A	N/A	N/A	N/A		

Fig. 4-2 National War College Second Floor Space Inputs

B.2 View Dynamic Glass Inputs and Tinting Schedule

B.2.1 View Dynamic Glass Inputs

In the performance assessment, the only differences between the baseline model and the calibrated model are the window performance properties. The baseline model uses single-pane U-0.53, SHGC-0.53 windows, while View Dynamic Glass in the calibrated model switches between Tint 1 state and Tint 4 state listed in **Table 4-5**.

Table 4-5 View Dynamic Glass Properties

Tint Level	Center-of Glass U-Value (Btu/sf/hr/°F)	Overall U-Value (Btu/sf/hr/°F)	Solar Heat Gain Coefficient	Corresponding Solar Incidence Level in Model (Btu/sf/hr)
Tint 1 (Modeled Clear)	0.22	0.35	0.28	<25
Tint 2	0.22	0.35	0.24	N/A
Tint 3	0.22	0.35	0.20	N/A
Tint 4 (Modeled Tinted)	0.22	0.35	0.18	>25

B.2.2 View Dynamic Glass Tinting Schedule

To verify that the modeled View Dynamic Glass only tints during times when the solar incidence level is high, the tinting schedule was extracted from the model outputs and plotted in **Fig. 4-3**. It shows more tinting near noon time than early morning and late afternoon, as well as more frequent tinting in the summer than in the winter, which matches how the glass is controlled in reality.

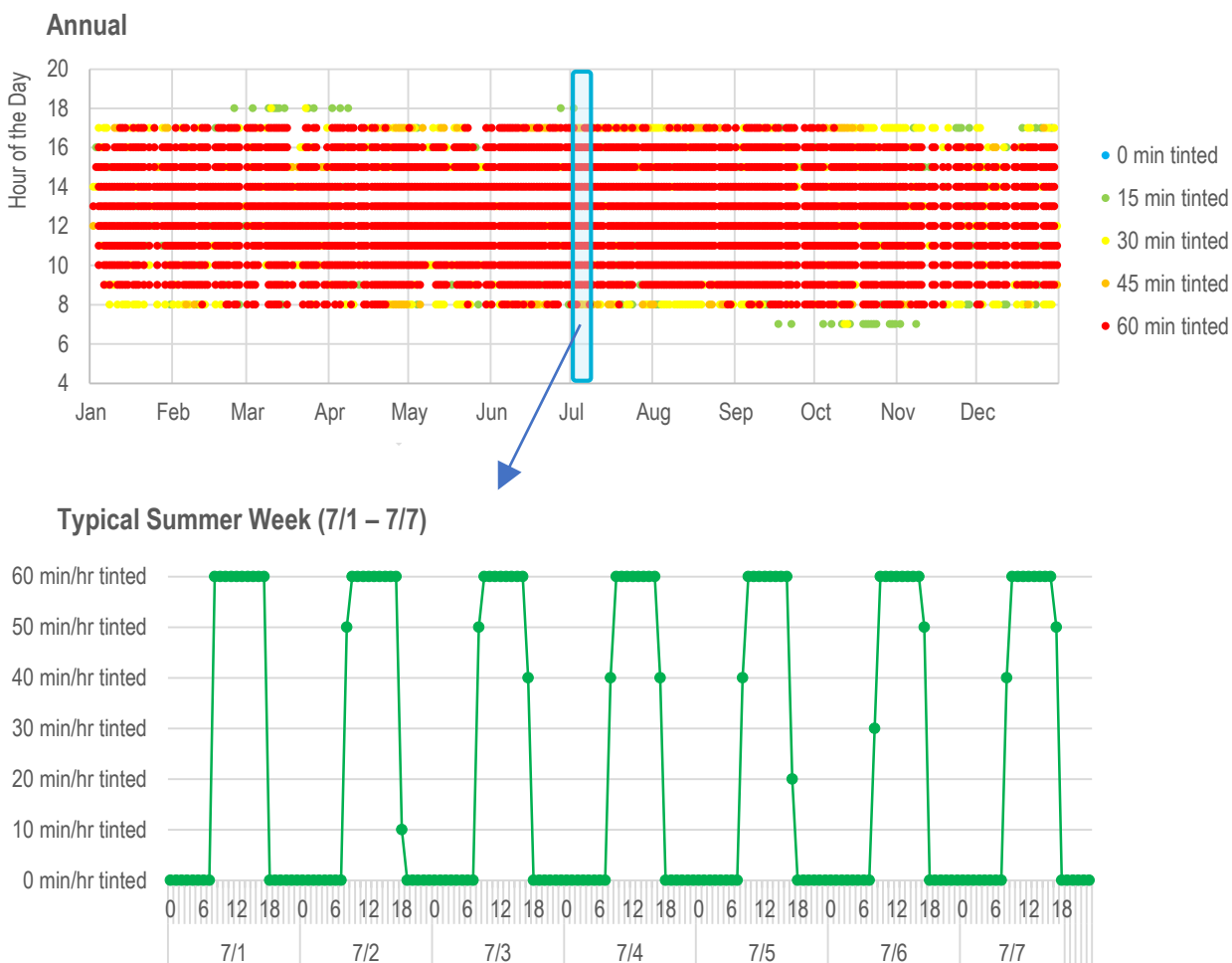


Fig. 4-3 View Dynamic Glass Tinting Schedules

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APPENDIX B COMFORT ANALYSIS

Comfort Analysis Report

National War College
Washington, D.C.

December 7, 2016

Prepared by:



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Contents

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1.0 Executive Summary

Measurements were taken to assess comfort for spaces with and without View Glass electrochromic glazing at the National War College. While differences in the internal window surface temperature were seen, ASHRAE 55 comfort analysis suggests negligible differences in comfort between spaces with identical solar exposure.

Differences in solar exposure were observed where second floor spaces were in direct solar, resulting in much higher interior surface temperatures on the perimeter – well over 100F for the frames – which were predicted to have an impact on occupant comfort. The high temperatures of the frames when in direct solar exposure could also result in localized occupant discomfort if they were standing directly adjacent to the window from the sensible difference in radiant temperature between the window/frame and the balance of the room.

2.0 Results Summary

The National War College building offered an opportunity to compare the comfort of similar spaces with and without View Glass electrochromic glazing. The definition of comfort defined by ASHRAE Standard 55 was used, with site measurements of air temperature, humidity, and radiant surface temperatures taken. Surface temperatures were determined through use of infrared photography (using a FLIR D60 camera).

The ASHRAE 55 comfort analysis found similar results between spaces with and without View Glass.

For the pair of rooms that had similar direct solar exposure (233 and 133), the View Glass had a 10F lower interior glass surface temperature than the traditional glass pane, (85F vs 95F). As expected, both rooms had the same frame temperature of approximately 100F.

While the lower window temperature does impact occupant comfort, at the seating location 6' from the window the air temperature and floor/ceiling/wall temperatures dominated and resulted in the Predicted Percent Dissatisfied being calculated as the same at 5%. The air temperatures in these two rooms were also the same, which suggests similar radiant temperatures since the same air temperature setpoints were in use.

It was observed that the blind position was different, with the louver blinds fully dropped in the traditional glazing room but half open in the View Glass space. This is as expected with the electrochromic glazing offering glare control without blind use.

A second pair of rooms was measured, Rooms 220 and 120. The results from these rooms showed a marked impact from differing solar exposure between the two rooms. The second floor room with View Glass, Room 220, had direct solar incident on the window while the first floor room did not. As a result, the View Glass interior surface temperature was 9.5F higher than the standard glazing, which was not exposed to direct solar. The frame temperatures showed a much higher 28F temperature difference, with the frame in direct solar measured at 109F – appreciably hot to the touch.

The difference in observed window and frame surface temperature differences were large enough to result in a difference in the comfort metric between the two spaces, with the View Glass space resulting in a 7% Predicted Percent Dissatisfied versus 6% for the standard glazing space (which was not in direct solar). The room in direct solar was also observed to have a lower air temperature, 71.4F versus 72.2F, which helped compensate for the higher radiant temperatures at the exterior. The difference in solar exposure between the first and second floor rooms would be expected to impact occupant comfort.

3.0 Methodology

Comfort analysis recognizes that comfort is a function of not just the thermostat temperature (referred to as the dry bulb temperature), but also the local air velocity, the space humidity, and the radiant temperature (which can vary radically from the air temperature for external windows).

ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces. Analytical calculations for the test spaces were performed using the ASHRAE Thermal Comfort Tool software available from the ASHRAE.

Thermal comfort stems from two components: (1) whole body thermal comfort and (2) local thermal comfort. These elements, defined below, are calculated using the following data inputs:

Table: Data Used In Thermal Comfort Metrics

Aspects Of The Thermal Environment	Characteristics Of Occupants
Air Temperature	Metabolic Rate
Air Velocity	Clothing Insulation
Air Turbulence	
Mean Radiant Temperature	
Individual Surface Temperatures	

These comfort factors were assessed for specific occupant locations during the site visit. Representative challenging comfort locations, such as a seat closest to a window and farthest from a window were examined. The site information collected included the following information for each location:

Whole Body Thermal Comfort

Whole body thermal comfort pertains to the sensation of the entire body and accounts for factors such as air temperature, air velocity, mean radiant temperature, clothing, and metabolism. The overall radiant temperature of the room was the primary variable impacted by the type of glazing.

Local Thermal Comfort

Local thermal comfort relates to specific body areas and covers metrics such as draft, warm and cold surfaces, and air temperature difference between head and ankles. The local radiant temperature at the exterior wall was the primary variable impacted by direct solar driving up the temperature of the frame and, to a lesser extent, the interior pane of the window.

4.O Data and Analysis Output Summary

Room 220

ASHRAE Standard 55-2004 Comfort Model

File Options Help

Model: PMV

Environmental Conditions

Air Temperature: 71.4 °F

MRT: ☐ Link with air 78.0 °F Calc

Air Velocity: ☐ Occupant control 25.0 fpm

Relative humidity: 61 %

Activity

Metabolic rate: 1.0 met

Clothing

Pants, shirt, t-shirt, suit jacket, briefs, shoes

Clothing level: 1.17 clo

Results

✓ PMV: 0.31 Neutral

✓ PPD: 7 %

✓ Humidity ratio: 0.010

✓ Draft Risk: 12 %

Compliance

✓ Complies with Standard 55-2004

Room 120

ASHRAE Standard 55-2004 Comfort Model

File Options Help

Model: PMV

Environmental Conditions

Air Temperature: 72.2 °F

MRT: ☐ Link with air 75.8 °F Calc

Air Velocity: ☐ Occupant control 25.0 fpm

Relative humidity: 60 %

Activity

Metabolic rate: 1.0 met

Clothing

Pants, shirt, t-shirt, suit jacket, briefs, shoes

Clothing level: 1.17 clo

Results

✓ PMV: 0.23 Neutral

✓ PPD: 6 %

✓ Humidity ratio: 0.010

✓ Draft Risk: 12 %

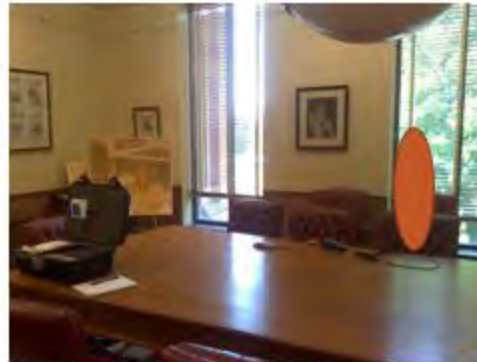
Compliance

✓ Complies with Standard 55-2004

Room 220, 9/1/2015 12 noon



Room 120, 9/1/2015 11:20AM



Room 233

File Options Help

Model: PMV

Environmental Conditions

Air Temperature: 70.3 °F

MRT: ☐ Link with air 73.1 °F

Air Velocity: ☐ Occupant control 25.0 fpm

Relative humidity: 63 %

Results

✓ PMV: -0.07 Neutral

✓ PPD: 5 %

✓ Humidity ratio: 0.011

✓ Draft Risk: 13 %

Activity

Seated, quiet

Metabolic rate: 1.0 met

Clothing

Pants, shirt, t-shirt, suit jacket, briefs, shoes

Clothing level: 1.17 clo

Compliance

✓ Complies with Standard 55-2004

Room 133

ASHRAE Standard 55-2004 Comfort Model

File Options Help

Model: PMV

Environmental Conditions

Air Temperature: 70.3 °F

MRT: ☐ Link with air 73.4 °F

Air Velocity: ☐ Occupant control 19.7 fpm

Relative humidity: 63 %

Results

✓ PMV: 0.01 Neutral

✓ PPD: 5 %

✓ Humidity ratio: 0.011

✓ Draft Risk: 9 %

Activity

Seated, quiet

Metabolic rate: 1.0 met

Clothing

Pants, shirt, t-shirt, suit jacket, briefs, shoes

Clothing level: 1.17 clo

Compliance

✓ Complies with Standard 55-2004

Room 233, 9/1/2015 10:40AM



Room 133, 9/1/2015 11:00AM

